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Significance of the Effect of Nitrogen Application on the Engineered Bioremediation of Crude Oil in a Salt Marsh.

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SIGNIFICANCE OF THE EFFECT OF NITROGEN APPLICATION ON THE ENGINEERED BIOREMEDIATION OF CRUDE OIL IN A SALT MARSH

A Dissertation

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by
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Abstract

The biodegradation of the crude oil in a salt marsh was monitored by tracking the decline of the ratio of various components in the crude oil to a stable marker, hopane. In studies of mesocosms, addition of nitrogen as ammonium nitrate resulted in more rapid biodegradation of the oil at 0.10 significance. In field plots, addition of nitrogen was found to not significantly increase the rate of oil degradation over the rate in the control plots.

The degradation of the oil is best described by a first order decay equation. The kinetic rate parameter k was 0.0054/day in the control field plots. Average kinetic parameters for control plots for various n-alkanes from dodecane to dotriacontane were within the range of 0.0034 to 0.0078/day. Kinetic parameters for the mesocosms were approximately three times faster than for the field plots.

The findings are strictly applicable only to the conditions of the research, i.e., Louisiana sweet crude oil, application rate of 1.16 kg/square meter, a salt marsh populated by *Spartina alterniflora*, and application of the oil in late summer. The findings may, however, be considered a point of beginning for similar but not identical situations. While nutrient addition to the field plots was not significantly beneficial to biodegradation under the subject conditions, under other situations it may offer significant improvement of degradation rates. A logic diagram to determine whether a given spill in a marsh should have nutrients added is presented. A scenario with a work plan and budget outline to conduct a pilot nutrient application in the case where nutrient addition is indicated as beneficial is presented in Appendix H. The scenario continues through budget preparation for full scale field application of the nutrients.

1. Introduction

1.1 Objectives

Louisiana's wetlands are vulnerable to spills of crude oil since many of the extraction wells lie in the coastal marshes, and oil pipelines bringing the crude oil also cross through the coastal marshes. Much study has been done of bioremediation of crude oil, particularly in the aftermath of the Exxon Valdez release. Most of the studies, however, are not applicable to South Louisiana since the coastal marshes of Louisiana are an organic rich, temperate ecosystem, while the previous studies have been done on cold, high energy, nutrient poor beaches. Studies are, therefore, necessary specific to the Louisiana coastal marshes.

Work on the topic has been ongoing for several years at Louisiana State University. Jackson (1996) studied 1) role of nutrients relating to crude oil degradation in a salt marsh, 2) seasonal variation and response to nutrients in both fresh and salt marsh, and 3) use of stable carbon isotopes to monitor mineralization. This dissertation research builds on the foundation established by Jackson (1996) to determine whether nutrient applications prove beneficial to biodegradation on a small (6 foot by 6 foot) field plot scale and to develop engineering procedures to monitor and predict the outcome of the bioremedial process in the field. The emphasis is on converting bioremediation from a serendipitous occurrence to a carefully orchestrated engineering task which accomplishes a maximum of performance per dollar spent.

The three objectives are to: (1) Determine in the laboratory the form and application rate for nutrients which, when supplied, are both effective and economical in enhancing crude oil degradation in a salt marsh, (2) Confirm the laboratory developed conclusions regarding application rate of nutrient amendments by application in the small scale field plots, and determine

parameters measurable on a near-real time basis in the field, which will correlate with optimum biodegradation, and (3) Evaluate the feasibility and economics of full scale field application of the oxygen and nutrient formulations to an actual spill.

1.2 Background

Coastal marshes are susceptible to spills or discharges of crude oil. Furthermore, the behavior of coastal marshes once impacted by such spills, is different from other habitats, such as cold water beaches, which have already been studied in greater detail. Additional research is needed to optimize recovery of the marshes via bioremediation following spilling of crude oil.

Louisiana has 40 percent of the United States' coastal wetlands and 15 percent of the United States crude oil production. Much of Louisiana's oil production is located in the coastal marsh where canals are dredged to obtain access to the wells. Collection pipelines and/or liquid containing barges transport the extracted crude oil from the wells to larger collection facilities and then to refineries. Imported oil also arrives at the Louisiana coastline in a pipeline crossing through the coastal marshes. The pipeline conveys it to refineries or storage locations of the Strategic Petroleum Reserve.

Much study of the fate of spilled oil has taken place, especially since the release of oil from the Exxon Valdez in 1989. Studies of the behavior of spilled crude oil and refined petroleum products are also available from terrestrial spills such as from above-ground and underground storage tanks. In open water, the processes for recovery from the effects of the spilled oil include volatilization, photolysis, and dispersion. In the unsaturated zone, which is important in terrestrial spills, the main processes are transport and biodegradation. Behavior of spilled oil in a marsh has characteristics of a spill in open water and characteristics of a spill in the unsaturated zone. In the marsh there is a free water surface, but

volatilization and dispersion are inhibited by vegetation. Vertical transport in the soil or sediment is not as free as in the unsaturated zone, since the soil and sediments are normally saturated and a strong downward gradient is absent. Access of the spilled contaminants to the atmosphere or even to the water column may be short lived, since periodic influx of additional sediment may bury the contaminants. The process of recovery of a marsh, therefore, includes volatilization and dispersion, subject to the limitations described above, but more predominantly biodegradation.

The extensive research done on beaches after the Exxon Valdez spill is not fully applicable to marshes. Beaches represent a cold water, high energy environment, while Louisiana marshes are a temperate, highly organic, oxygen deficient, biologically rich environment. Initial cleaning of spilled oil from beaches is often accomplished by high pressure, high temperature water washing. The mechanical cleaning used on beaches is not appropriate to use in the marsh since it would destroy the sensitive vegetation which defines the marsh ecosystem. If mechanical washing is used in the marsh as an initial spill response, damage to the marsh is minimized by preventing response teams from trampling the marsh. During the cleanup following the Lake Barre oil spill in coastal Louisiana in 1997, the daily instructions forbade cleanup crews from entering the marsh (Texaco, 1997). To remove oil, Hoff et al (1993) found that low pressure, ambient temperature washing with vacuuming was the optimum response technique in a *Salicornia / Distichlis* marsh. The technique lifted the oil off the surface without uprooting plants or trampling sediments. Because marshes can tolerate less vigorous washing than beaches, bioremediation will be depended on to a greater degree in marshes than for other ecosystems to effect the final recovery.

Petroleum is an extremely complex mixture of hydrocarbons, with hundreds of individual components. Atlas (1981) categorizes petroleum into three classes based on related structure. These classes are the saturate or aliphatic fraction, the aromatic fraction, and the asphaltic or polar fraction. The hydrocarbons within the saturate fraction include *n*-alkanes, branched alkanes, and cycloalkanes. *n*-alkanes are generally considered the most easily degradable, branched alkanes are considered intermediate in degradability, and cycloalkanes are considered among the most persistent compounds (Atlas, 1981). Light aromatic hydrocarbons are subject to evaporation and microbial degradation. Condensed ring aromatics are less susceptible to degradation, with the degradation rate for naphthalene being over 1000 times the degradation rate for benzopyrenes (Atlas, 1981). Metabolic pathways for degradation of asphaltic compounds are not well understood, and these compound are difficult to analyze using existing methods (Atlas, 1981).

Biodegradation of crude oil in the marsh is especially problematic since wetland sediments are primarily anaerobic while biodegradation of petroleum hydrocarbons occurs most rapidly under aerobic conditions. The limited diffusion of oxygen through the water column and the overwhelming demand of petroleum in the wetland sediment result in anoxic conditions in all but the upper few millimeters of sediment at the water/sediment interface. The continual influx of new sediment effectively moves the contaminant continuously farther from the aerobic zone.

More study is needed of the conditions to optimize recovery of marshes from oil spills.

1.3 Literature Review

The literature review considers past studies into

- What are the possible fates of oil spilled in a wetland? - Section 1.3.1
- What is the nature of the harm done by oil to a salt marsh, and what factors control the degree of damage done? - Section 1.3.2
- What are the conclusions from past studies of crude oil bioremediation in general? - Section 1.3.3, and
- What recent research has been done specific to Louisiana's coastal marshes? - Section 1.3.4

1.3.1 Fate of Oil after a Wetland Oil Spill

The most complete mass balance accounting, encountered by the writer, of spilled oil was done after the Exxon Valdez spill. Wolfe et al (1994) estimated that, by 1 1/2 years after the spill, about 20 percent of the spilled oil evaporated and underwent photolysis in the atmosphere, about 50 percent biodegraded either on beaches or in the water column, about 14 percent was recovered and disposed of, 13 percent remained as highly weathered residuals in subtidal sediments, 2 percent remained on intertidal shorelines, and 1 percent remained in the water column. These percentages will likely be different in a coastal marsh, but they give an idea of the relative importance of the different processes.

In the Lake Barre oil spill, an estimate 3.5 hours after the spill was discovered estimated 35 percent had evaporated (Texaco, 1997).

In a coastal marsh, the writer sees the following short term fates as being possible for a spilled crude oil

- Floating of oil as a separate phase on the water surface
- Dispersion of oil into the surface water column

- Deposition of free phase oil onto the marsh sediment surface
- Infiltration of oil into marsh sediments at low tide
- Evaporation
- Dissolution into water column or porewater
- Sorption of oil onto plant surfaces, followed by later dispersion, evaporation, or dissolution

Longer term fates of the oil are

- Remaining undegraded on the sediment surface or within the sediment pores
- Degradation within the surface water column
- Degradation on the sediment surface or within the sediment pores
- Continued dissolution and evaporation

Once the oil sorbs to the marsh sediment, it has limited time to be degraded. Oil components typically degrade most rapidly under aerobic or oxidized soil conditions. Oxidized soil conditions occur only in the upper 5 to 10 mm of Louisiana marsh sediments. In addition, dead plant material and sediment may be deposited into the marsh at a rate on the order of 1 cm per year, so that contaminants initially deposited into the upper oxidized zone are quickly buried and relegated to the reduced zone where biodegradation is generally conceded to not occur rapidly (DeLaune et al, 1990). Caldwell et al (1988), however, found that a well abiotically weathered North Slope crude degraded rapidly (nearly completely in 201 days) in an anaerobic slurry made with acclimated sediment. Long chain n-alkanes (C_{15} to C_{34}), previously thought not to degrade anaerobically were degraded. Based on the close stoichiometric balance between oil degraded and sulfate concentration, sulfate reduction was concluded to be the electron acceptor process.

While anaerobic conditions may not hinder degradation as much as formerly believed, a thick oil layer is a hindrance to degradation. In a study of thicker (several cms) spills, Baker et al (1993) found that 15 and 18 years after the spills, degradation was not complete and in some areas had barely begun. Sediment deposition on the surface masked the impact of the undegraded oil underneath in some cases. Vegetation was also able to grow on the newly deposited sediment over the oil or to grow from unimpacted soil below the oil layer, through the oil, and spread its leaf surface above the oil.

Most chemical and biochemical reactions take place in the aqueous phase. It is, therefore, important that the spilled oil becomes dispersed or dissolved in order to make it available to the microbes. Certain microorganisms can produce surface active compounds that emulsify oil in water and facilitate removal by degradation of the emulsified oil. Juwarkar et al(1993) studied two biosurfactants produced by *Bacillus subtilus* and *Bacillus licheniformis* JF-2 which reduced the surface tension of the water at low concentrations.

1.3.2 Impacts of Oil Spills to Wetlands

The impact of an activity on the marsh is measured by the impact to the vegetative community. In a Louisiana salt marsh, this vegetative community is predominately *Spartina alterniflora*. *S. alterniflora* gives the marsh structure and provides habitat for the creatures that live there. Destruction of the *S. alterniflora* is equivalent with destruction of the salt marsh by conversion to open water.

Evaluation of damage to the marsh from oil spills has focused either on the shorter term or the long term. Short term effects usually relate to foliage appearance. Relating to the shorter term, literature disagrees on the effect of oil release on a marsh. Some studies indicate severe damage to the plants, while others indicate little damage. The parts of the marsh vegetation contacted by the

oil appear to control the variability in the amount of damage done to the vegetation. The fluctuation in water levels controls the parts of the marsh plants which receive an oily coating. Mendelssohn et al (1990) cite cases where oil addition resulted in death of vegetation and reduced regrowth, cases of no effects a year after oil application, and cases of increased growth after oil application. Rates of oil application varied from 0.82 to 6 liters per square meter of marsh. In the particular case examined in the field by Mendelssohn et al (1990), a spill of only 0.82 liters per square meter was found to have had a significant impact on a brackish marsh. The writers speculated that the damage was more severe due to an unusually large tidal variation which resulted in coating of 30 to 70 percent of the vegetative canopy as well as penetration of oil 15 to 20 cm into the marsh substrate.

Smith et al (1984) studied the effect of oil on *S. alterniflora* in a salt marsh. They applied south Louisiana crude oil at a rate of 2 liters per square meter and found that oil on the surface soil or water had little influence on mature *S. alterniflora* under conditions of normal tidal variation of 20 to 30 cm. They surmised this lack of deleterious effect was because tidal water did not contact the leaf blades. They referenced an earlier study, however, in which significant damage had occurred, probably due to unusually high tides coating the leaves to a height of 50 cm. Smith et al (1984) report some impact to photosynthesis was found to occur at 6 days after oil application, but was short lived, with full recovery of photosynthesis by 13 days after oil application.

Alexander and Webb (1987) examined the long term, i.e., 1 to nearly 3 years, effects of varying concentrations of crude oil in sediments in a *S. alterniflora* marsh. The study took place in the aftermath of a ruptured pipeline in the Galveston Bay system. They found that if oil concentrations in sediment were

less than 5 mg of oil per gram of sediment, the growth of *S. alterniflora* was not affected. Greater concentrations however, affected growth with the amount of effect, as measured by live stem density, proportional to the concentration of oil. Alexander and Webb's (1987) study supported previous conclusions by Krebs and Tanner (1981) that concentrations of 1.5 to 2 mg/g had no effect on plant growth but concentrations of 5 to 17 mg/g resulted in adverse effects, including root kill. The aftermath of root kill was exposure of roots in waterway banks, and erosion of the marsh into open water. Alexander and Webb (1987) philosophized that DeLaune et al's findings of no adverse effects at up to 30 mg/g oil to sediment concentration was due to DeLaune et al's (1979) smaller plots which allowed plants access to oil free areas nearby.

The findings of Alexander and Webb (1987) apply to a single type of crude (Libyan), in a single ecosystem (Dickinson Bayou area of Galveston Bay), with a given set of meteorological conditions following the spill. They believed that prolonged low tides after the spill allowed more oil to seep into the sediment than would have occurred if a high tide had removed the oil more quickly. Variables which Alexander and Webb (1987) believe important include amount of oil spilled; viscosity of oil, with a thinner oil having greater penetration; and sediment texture - clay impedes oil entry, while root matter or sand allow easy entry.

Alexander and Webb (1985) also attempted to study the effects of season of spill and type of oil spilled on *S. alterniflora*, since they considered this plant to be responsible for the productivity and habitat value of salt marsh. Four different oils were applied at different application patterns and rates. No. 2 fuel oil was found to be more damaging than either No. 6 fuel oil or Arabian or Libyan crude oil. Season of the year of spill influenced the amount of damage only when complete plant coverage by the oil occurred. Alexander and Webb suggested that

long term damage occurs due to total blockage of plant air space opening, which prevent *S. alterniflora* from transporting oxygen to its roots and maintaining a high redox potential in surrounding soil.

The impact of the oil spill in a wetland can also be examined by the risk it poses to the humans using the wetland or the impact to the habitat and animal species of the wetland. A formal or informal risk assessment may be conducted which evaluates the exposure pathways and allowable exposures depending on the site use. The Louisiana Department of Environmental Quality's Risk Evaluation/Corrective Action Program (RECAP) (LDEQ, 1998) provides a methodology for assessing the risks to human receptors.

Since an oil spill would involve release to a surface water body, an ecological risk assessment would be the means to determine the impact to primary, secondary, and possible tertiary animal receptors. The RECAP document (LDEQ, 1998) provides a checklist to determine when an ecological risk assessment should be conducted, and very limited (3 pages) guidance on the procedures for conducting one.

1.3.3 Past Studies of Biodegradation

Atlas (1981) published an excellent paper of what was known up to that time concerning the microbial degradation of petroleum hydrocarbons. Atlas (1981) discusses differences in degradability of different petroleum fractions, groups of microbes shown to be capable of degrading petroleum, the effect of oil spillage and nutrient availability on microbe counts in nature, the effect of the physical state of oil on degradability, and proportions of oxygen and nutrients required for biodegradation. Most of the situations referenced in Atlas (1981) are to open water behavior or behavior of oil upon impingement to a beach. Few references are made to coastal wetlands, and no references are made to

Louisiana salt marshes. Atlas (1981) provides a framework for the conceptual model for the study of petroleum degradation, namely, that petroleum is a complex mixture of hydrocarbons; biodegradation is brought about by consortia of microbes, rather than a single family; microbes capable of petroleum biodegradation are ubiquitous; population densities of hydrocarbon degrading microbes increase in areas of historical petroleum spillage, but only if nutrients, particularly nitrogen and phosphorous are available; and degradation does not occur in the hydrocarbon phase, therefore increases in surface area, emulsification, and dissolution are important factors in speeding biodegradation.

Leahy and Colwell (1990) also presented a review of the state of knowledge regarding microbial degradation of hydrocarbons. Their review was not as complete as Atlas (1981), but incorporated more recent references, and discussed the mechanisms by which microbes become adapted to degrade hydrocarbons. No references to Louisiana salt marshes were included in Leahy and Colwell (1990).

Quantitation of degradation of crude oil is often done by comparing mass of various fractions such as alkanes and polyaromatic hydrocarbons (PAHs) before and after degradation. The total mass of oil may also be compared against a stable marker. After the Exxon Valdez spill, the amount of degradation of crude oil was based on determining the amount of oil remaining compared to the remaining amount of hopane, a very slowly degrading cycloalkane compound. Based on the analysis of the crude oil spilled, each kilogram of crude oil, after simulating initial evaporation by heating to 521°F, was found to contain 300 mg of hopane. Therefore, wherever 300 mg of hopane was subsequently found, it was concluded that 1 kg of oil had originally been there. The annual rate of biodegradation of

crude oil found in this manner was 2.2 grams per kilogram of beach sediment (Prince, 1992). Hopane has been used as the stable marker in this study also.

Huesemann (1995) stated that the extent of hydrocarbon degradation was dependent on 1) the presence of hydrocarbon degrading bacteria, 2) the creation of an optimum environment for stimulation of biodegradation, 3) the predominant petroleum hydrocarbon types in the contaminated matrix, and 4) the bioavailability of the contaminants to the degradative bacteria. By creating an optimum environment and ensuring adequate bacteria counts, Huesemann was able to study the effect of the various hydrocarbon types and determine that even the more poorly soluble compounds were sufficiently bioavailable so that bioavailability was not the controlling factor. He then devised a scheme of classifying hydrocarbons by compound classes and determined the degree of attainable biodegradation of each class. Using this scheme, a hydrocarbon which had not yet been subjected to biodegradation could be categorized based on the proportion of compounds in each class. The biodegradability of each class would then be multiplied by the percent of the total represented by that class and the process summed across all classes to determine a predicted degree of biodegradability for the oil.

Research by Carmichael et al (1997), however, indicates that bioavailability may be a controlling factor when dealing with aged hydrocarbons as opposed to hydrocarbons applied for testing in a laboratory. Carmichael et al (1997) found that desorption rates of ^{14}C phenanthrene and chrysene applied to soil was faster than the mineralization rate of these compounds, but desorption rates of native PAHs in higher organic content contaminated soils were slower than mineralization rates.

Researchers generally agree that biodegradation is limited by either oxygen, nutrients, or appropriate microbes. In most cases the researchers concede that adequate population of oil degrading microbes will develop, providing that microbial populations have previously been exposed to oil, and if nutrients are available. In at least two cases, (Mearns et al, 1993, and Venosa et al, 1996), however, adding of microbes was attempted.

Mearns et al (1993) discuss efforts to enhance bioremediation in August 1990 after a spill in Galveston Bay, Texas. The spill consisted of 692,000 gallons of a non-sticky catalytic feedstock oil, similar to a 10W-50 motor oil. The marsh is described as a salt marsh vegetated with *Scirpus*. Microbes and nutrients were sprayed onto test sections of Marrow Marsh, but enhancement of biodegradation was not clearly observable over the short time period of the exercise. The Mearns et al (1993) paper gives a good description of the delivery method for microbes and nutrients - spraying through a high pressure hose. Mearns et al (1993) concluded that the treatment technology was logistically feasible and did not result in additional damage to natural resources, health, or safety beyond a no action alternative.

Mearns et al (1993) suspected that failure to observe enhancement of biodegradation was possibly attributable to too short of an observation period, pre-existing ample microbe and nutrient concentrations in the untreated areas as supplied by local cattle, or toxicity of micronutrients such as copper in the nutrient formulation used.

Nadeau et al (1993) were also involved in the Marrow Marsh bioremediation study. They note that pre-spill planning and after spill planning are needed to insure that appropriate sampling, analyses, and preservation of control areas are maintained. Despite the failure of the Marrow Marsh project to

demonstrate biodegradation, Meams et al (1993) present much real data and practical experience such as:

- TPH concentrations from the spill were 397 to 410,100 mg/kg wet weight
- Ammonia-N concentrations in untreated areas were 0.03 and 0.05 mg/l
- Ammonia-N concentrations in treated areas were 0.87 and 1.17 mg/l
- A pump and fire hose arrangement was able to deliver nutrients dissolved in water a distance of 30 to 50 feet.

Venosa et al (1996) applied oil to a set of beach plots in Delaware. They found no significant difference between the crude oil biodegradation in the plots receiving bacterial innoculants and nutrients, and the plots receiving nutrients without bacteria.

Much of our knowledge of biodegradation of oil comes from the aftermath of the Valdez spill. Bioremediation was attempted on the beaches where, presumably, oxygen would not be the limiting factor. Nutrient supplements were, therefore, used to stimulate biodegradation.

After the Exxon Valdez spill, several fertilizer formulations were tried to speed bioremediation, and one of these, Inipol EAP22, a microemulsion of a saturated solution of urea in oleic acid, showed dramatic results on cleaning oil from beach cobbles. Since the EAP22 was oleophilic it did not penetrate deeply into the beach and was effective in promoting biodegradation of the on-the-surface oil. For subsurface bioremediation, a slow release encapsulated formulation of ammonium nitrate and ammonium phosphate (Customblen 28-8-0) was used. The Customblen resulted in increases of nutrients 5-10 fold in the

beach for at least 30 days after the application (Prince, 1992). Microbial counts found 10 to 100 times as many bacteria, both heterotrophic and oil-degrading, on sediments on beaches that received fertilizer within the past month or two. The microbial count studies also resulted in the conclusion that monthly reapplication of fertilizer was necessary (Prince et al, 1993).

In another study of fertilization in the wake of the Valdez spill, Bragg et al (1993) concluded that fertilization with either EAP22 or Customblen increased the rate of degradation 3 to 5 times. They concluded that degradation depended on the amount of nitrogen delivered into the pore space per unit of oil. In at least one case, despite nitrogen being applied to a beach, it did not successfully reach the pore space. Bragg et al (1993), therefore, recommended that the nitrogen content of the porewater itself should be the primary field monitoring parameter.

Field testing has also been done on simulated oil spills using fish and meat meals as accelerating agents for biodegradation. The animal protein, which has a nitrogen to phosphorous ratio close to that required by bacteria, resulted in increased bacterial counts in soil. Reapplication was required after 40 days (Bassere et al, 1993).

Lee et al (1993) studied the use of fertilizer, including time release formulations on biodegradation of a waxy crude oil, on a low energy sand beach in Nova Scotia. When expressed as n-alkanes, they found that 52.4 percent of the oil remained in the non-fertilized control after 167 days, while from 39.9 to 25.3 percent remained in the treatments with combinations of ammonium nitrate, phosphate, and coated urea. Lee et al (1993) recommended slow release fertilizers in water temperature over 15° C and soluble inorganic fertilizers in cooler water.

1.3.4 Recent Research at L.S.U.

This research is not conducted in a vacuum. For the past several years, researchers have been studying the behavior of crude oil degradation in the presence of marsh soil. This research is a continuation of that work, taking it into the field with larger plots and larger numbers of replicates over a longer period of time. The work which went before, however, pointed the way in terms of nutrients, nutrient application rates, and experimental techniques.

Jackson (1996) conducted numerous studies in non-oxygen limited slurries. Under the non-oxygen limiting conditions he determined that nitrogen can be a limiting nutrient, and that in a salt marsh degradation of the oil was minimal until nutrients were applied. He also found in these slurries that hexadecane showed improvement from nutrient application throughout the year, while phenathrene did not respond positively to nutrient addition in about half the months tested. In mesocosm studies he found that fertilizer at some concentrations resulted in better degradation than the control, while other concentrations were not beneficial. He also found a lesser rate of biodegradation of the alkanes compared to the PAHs. In a small scale field plot study using naturally occurring stable carbon isotopes, Jackson (1996) determined that application of ammonium did not enhance the production of CO_2 and suggested that oxygen limitation rather than nutrients may have been the controlling factor

The work by Jackson (1996) and later Shin (1998) advanced many of the procedures used in this research, namely:

- a uniform method for cutting marsh cores
- methods for constructing the glass cylinder mesocosms
- selection of appropriate scintillation cocktails when using radiotracers to monitor oil mineralization in the lab

- design of flow-through NaOH traps to capture CO_2 and radio-labeled CO_2
- procedures to extract oil from marsh soil and phase separate the extract.

Jackson (1996) also defined the concentrations in porewater at which nitrogen enhances biodegradation, and the areal application rate which resulted in the desired volumetric concentration.

1.3.5 Quantitative Comparison of Past Results

Much has been learned from past research, but the comparison of it is difficult. The engineering usefulness of this information will depend on the degree to which it can be compared and contrasted to take a course of action guided by the most relevant data.

The writer has attempted to compare the results of past studies based upon the rate at which the oil degraded. Table 1.1 summarizes the first order degradation rate, where it was either stated or can be reasonably inferred. The oil type, nutrient amendments, and ecosystem are described. Table 1.1 includes only field studies and intact mesocosm studies.

1.4 Preview of Remaining Chapters

As noted in Section 1.1, this research had three objectives which are satisfied in the next three chapters.

Chapter 2 presents the discussion of the laboratory mesocosms used to evaluate nutrients and application rates which were effective in enhancing crude oil degradation.

Chapter 3 presents the discussion of the field plot study which demonstrated the benefits (or lack thereof) of adding nutrients to a crude oil spill in the field. These two chapters are organized in usual scientific format, that is,

Table 1.1 Summary of Crude Oil Biodegradation Rates from Field or Mesocosm Studies

Study	Oil Type	Nutrients Applied	Ecosystem	K 1/day	Method of Determining
Lee et al., 1993	Waxy crude	None	Low energy sand beach	0.0039	52.4% left at 167 days
Lee et al., 1993	Waxy crude	N and P Fertilizer	Low energy sand beach	0.0055-0.0082	25.3 to 39.3% left at 167 days
Jackson, 1996	Sweet LA crude (alkanes)	None	Mesocosm of salt marsh core	0.008	20 % reduction at 4 weeks
Jackson, 1996	Sweet LA crude (alkanes)	NH_4, 0.1 to 10 mg/cm^2	Mesocosm of salt marsh core	0.014	32% reduction at 4 weeks
Jackson, 1996	Sweet LA crude (PAHs)	None	Mesocosm of salt marsh core	0.025	50 % reduction at 4 weeks
Jackson, 1996	Sweet LA crude (PAHs)	NH_4, 0.1 to 10 mg/cm^2	Mesocosm of salt marsh core	0.025	50 % reduction at 4 weeks
Venosa, 1996	Nigerian Bonnie Light, n alkanes C_{10}-C_{35}	Sodium nitrate and sodium tripolyphosphate	Delaware Beach	0.12 to 0.03 (lower k at higher C)	Kinetic parameters stated in paper
Venosa, 1996	Nigerian Bonnie Light, n alkanes C_{10}-C_{35}	None	Delaware Beach	0.04 to 0.02 (lower K at higher C)	Kinetic parameters stated in paper

introduction, explanation of materials and methods, results and discussion, and conclusions.

Chapter 4 evaluates the feasibility of applying nutrients to a full scale oil release and a program to put the findings of the research to work. Its organization is similar to that of a work plan. Its format is, of necessity, a mixture of discussion of budget, regulatory standards, and logic diagrams for modifying a course of action based on findings.

Chapter 5 is the overall conclusions and recommendations, and Chapter 6 is a list of references cited.

2. Mesocosm Tests of Nutrients

2.1 Introduction

The objective of this phase was to determine in the laboratory the form and application rate for oxygen and nutrients which, when supplied, are both effective and economical in enhancing crude oil degradation in a salt marsh.

The hypothesis is that a given nutrient formulation and application rate will result in better biodegradation of crude oil than no application of nutrients. This hypothesis was tested by applying oil and various nutrients and measuring the rate of oil degradation. In addition, other parameters, which could be measured more quickly or economically than crude oil degradation itself, were measured to determine secondary characteristics which might be indicative of enhanced crude oil degradation.

2.2 Materials and Methods

Previous work by other researchers at LSU demonstrated that addition of nitrogen to non-oxygen-limited marsh microcosms results in a more rapid degradation of the crude oil. Previous research (Jackson, 1996) had also established the approximate concentration of nitrogen in the porewater needed to result in this enhanced biodegradation, the approximate amount of nitrogen source on a mass per area basis that must be added to result in the desired porewater concentration, and the conclusion that ammonia is superior to nitrate as a nitrogen source.

During this phase of the research, within mesocosms, the writer applied nitrogen in different forms plus an oxygen releasing compound to determine which treatments or combination of treatments resulted in enhancement (beyond the rate of degradation in the control mesocosm) of biodegradation. Each mesocosm consisted of a 15 cm diameter glass cylinder into which was placed an intact and

properly oriented marsh sample, followed by application of oil and nutrients. The sample was sealed in an air tight and water tight manner and a controlled flow of air was piped into the mesocosm to insure that the head space above the soil remained aerobic. Water was also added as needed to keep the porewater near the marsh surface. Details of preparation of the mesocosms follow.

2.2.1 Marsh Sample Collection

Marsh samples were obtained in late March 1997 from a *Spartina alterniflora* marsh in the Pointe au Chien Wildlife Management Area in Terrebonne Parish, Louisiana. Each core of marsh was cut by hand using a sharpened aluminum cylinder slightly smaller than the inner diameter of the glass cylinder into which the marsh sample would be placed. Since biodegradation is believed to be the result of the respiration of microbes in the shallow soil zone rather than mediated by the plant itself, marsh samples were selected at locations between the individual *S. alterniflora* plants to avoid incorporation of whole plants which would lead to unnecessary heterogeneity between samples and possible vertical pathways for the oil to seep around plant stems deeper into the marsh samples. Care was taken to not compress the marsh samples during coring and the samples were extruded under their own weight into the glass core with the marsh surface at the upper surface of the sample. Prior to placing the marsh core into the glass cylinder, a plastic bottom had been sealed in an air and water tight manner to the bottom of the glass cylinder.

The glass cores were transported back to Louisiana State University in Baton Rouge, Louisiana in an upright position. For the next several days water was added as needed to allow any entrapped air to be displaced from beneath the marsh surface and to maintain the porewater level near the marsh surface.

2.2.2 Nutrient and Oil Applications

Three days after obtaining the marsh cores, the crude oil and nutrients were applied to the cores. The oil applied to the cores was a sweet Louisiana crude provided by Exxon Corporation. Characterization of the oil was made by GC/MS analysis of 33 targeted compounds to identify concentrations of alkane and non-alkane components. Prior to its application to the cores, the oil was artificially weathered to remove volatile components in a manner similar to that expected if the oil had floated in open water for a day or two prior to impinging on a salt marsh. Weathering was accomplished by placing the oil in a flask and sparging air through the oil for about three hours. Also prior to applying the oil a radiocarbon source, ^{14}C hexadecane was added to the oil to result in a total count per mesocosm of 150,000 counts per minute (0.07 uCi).

Twenty-five ml of oil (20.5 grams) were added to each core. This equates to an application rate of 0.116 grams per square cm, 1.16 kg per square meter, or 1.41 liters per square meter. The oil was poured from a graduated cylinder onto the marsh sample surface and the glass cylinder rocked gently back and forth to spread the oil evenly over the surface. The nutrients, to be described shortly, were then sprinkled evenly over the marsh surface and the mesocosm sealed shut.

Four marsh soil cores, not placed within glass mesocosm cores, had oil applied at the time the glass enclosed samples had the oil applied. The oil was extracted from these four cores two days after application to provide a fingerprint of the initial oil composition as influenced by the proportion of compounds in the oil, the marsh matrix, and the extraction procedure.

Treatments consisted of an oxygen releasing chemical, a nitrogen releasing source, or a combination of the two. Table 2.1 summarizes the number and application to each mesocosm. Some of the mesocosms had neither oxygen

Table 2.1 Summary of Mesocosm Nutrient Applications

Oil Applied?	ORC Applied?	Nitrogen Source	No. of Mesocosms
No	Yes	None	1
No	No	None	1
Yes	Yes	Ammonium Nitrate	6
Yes	Yes	Meister 120	6
Yes	Yes	None	6
Yes	No	Ammonium Nitrate	6
Yes	No	Meister 120	6
Yes	No	None	6

nor nitrogen supplied, and two mesocosms had neither nutrients nor oil applied. The oxygen release chemical was Oxygen Release Compound (ORC) manufactured and marketed by Regenesis Corporation of San Juan Capistrano, California. ORC is a patented formulation consisting of magnesium peroxide and other chemicals. When wetted, the magnesium peroxide reacts to form oxygen and magnesium hydroxide. According to the manufacturers literature, ORC is 25 to 35 percent magnesium peroxide with the remainder being primarily magnesium oxide. Although the total oxygen requirements for biodegrading the amount of oil added is expected to require hundreds of grams of ORC if ORC were the only oxygen source, only 20 grams of ORC were added to each mesocosm where it was used, due to the voluminous powdery nature of the material. Even in this limited quantity, the ORC formed a brittle cement-like pancake on the mesocosm surface.

Two forms of nitrogen were used in the experiment. The goal was to supply 3 mg N/square centimeter of mesocosm surface, an application rate found beneficial by Jackson (1996, 1997). The application rate of fertilizer, therefore, was a function of mesocosm surface area (177 square cm) and the amount of nitrogen in the fertilizer used.

One nitrogen application was a time release urea fertilizer. Meister 120 is a polyolefin coated urea, consisting of 40 percent nitrogen, and designed to release nitrogen over approximately 120 days. It is manufactured by Meister Corporation and distributed by Helena Chemical Company of Tampa, Florida. In those mesocosms where used, the Meister 120 was applied at a rate of 1.33 grams per core which equates to 7.5 mg total fertilizer or 3 mg N per square centimeter.

Ammonium ion was the other selected nitrogen source. Ammonium nitrate was the chosen form for ammonium application since it supplied nitrogen not only

as ammonia, which appeared to be the more useful nitrogen form from past experience, but also supplied nitrogen as nitrate. The nitrate could also act as an alternate electron acceptor. Sufficient ammonium nitrate was applied so the ammonium ion by itself would supply the targeted application of 3 mg N per square cm. This translated to an application rate of 3.03 grams per core. Considering the nitrate ion also, 6 mg N per square cm might be available as nutrients for biodegradation. The ammonium nitrate used was granular fertilizer obtained from a local feed and seed company.

2.2.3 Mesocosm Setup

After application of the oil and nutrients, plastic tops were sealed in an air tight manner onto the mesocosms by placing a continuous bead of silicone sealant around the junction between the cylindrical glass core and the flat plastic plate for the entire circumference of the glass column. Each top had three ports in it. One port consisted of a rubber stopper with glass tubing connected to plastic tubing which allowed air to be continuously provided from a bottled air source to the mesocosm. The second port with a rubber stopper, glass tube and plastic tubing conveyed air leaving the mesocosm to a NaOH reservoir to scavenge the carbon dioxide from the exiting air. The third port was normally kept sealed with a rubber stopper. By removing the rubber stopper, water could be applied periodically to the mesocosm to stimulate a rainfall event and to keep the pore water near the marsh surface. This port was also used to insert a needle attached to a syringe to extract a pore water sample to measure pH, dissolved oxygen (DO), and ammonia in the pore water.

Air supplied to the mesocosms was class D breathing air supplied in 90 cubic foot 2200 psi cylinders. The air was sparged through a 1 N NaOH solution to remove carbon dioxide prior to introduction to the mesocosms. Periodically the

pH of the sparge water was checked to be sure the NaOH still had scavenging capability, and it was changed approximately every air bottle. pH levels in the sparge water when changed always indicated residual scavenging capability. During the time the mesocosms were operated, monitoring took place and water was added periodically to maintain a water level approximately at the marsh surface within each mesocosm.

2.2.4 Monitoring

Monitoring of the performance of the mesocosms was by means of

- Analysis of crude oil compounds - Section 2.2.4.1,
- Measurement of porewater parameters - Section 2.2.4.2, and
- Measurement of carbon dioxide evolution - Section 2.2.4.3.

2.2.4.1 Analysis of Crude Oil Compounds

The direct method of monitoring progress of biodegradation involved the analysis of oil extracted from the mesocosms. At the time the mesocosms were set up, four cores not contained in glass cylinders were oiled (including the ^{14}C tracer) with the same amount of oil as the mesocosms. Two days later the oil in these four cores was extracted and the oil components analyzed to define initial conditions in the cores. The extraction procedure for these cores and all subsequent mesocosms is described in Appendix A.

Thirty-three compounds were analyzed for in the GC/MS run. These are listed in Table D.1 of Appendix D. Not all the compounds were found at sufficient concentrations to conduct comparisons between treatments, however.

The alkanes were generally found in the oil at much greater concentrations than the PAHs. Of the compounds eluting over the time frame, 14 compounds (n-alkanes from undecane to hexatriacontane, plus pristane) and hopane were used to fingerprint the oil. The other compounds were not used either because they

were not detected at all or were detected at very small concentrations in the oil. Figure 2.1 depicts the compound to hopane (C/H) ratio for each of these compounds, providing an initial fingerprint of the oil. The standard deviation of the C/H ratio for each compound is also depicted on Figure 2.1 as an error bar.

Two replicates of each treatment (12 mesocosms total) were dismantled for oil extraction at 43 days, at 71 days, and at 133 days after oil application. The intervals at which to sacrifice the mesocosms for oil extraction were based on the measurement of radiolabeled carbon dioxide production.

Since the efficacy of extraction will vary from sample to sample, monitoring of oil components was done not for the absolute mass of each component found, but for the ratio of the mass of each component compared to the mass of a stable marker, in this case hopane. Hopane had been concluded in the studies after the Exxon Valdez release (Prince, 1994) to be the most stable of several "stable" markers considered. Figure 2.1 shows the average ratio of each of the components to hopane in the initial four cores sacrificed and also the standard deviation of the compound to hopane ratio as determined by the four cores.

2.2.4.2 Measurement of Porewater Parameters

The chemical character of the porewater in the mesocosms was tracked to determine if changes in chemical character could be used to indicate either suitable or unsuitable conditions for biodegradation of the oil.

After the mesocosms were settled in and the initial operating complications (air or water leakage, uneven air flow, etc.) worked out, porewater from the mesocosms was sampled on a weekly basis. Porewater was extracted through a port on top of the mesocosm using a long needle attached to a syringe. About 5 ml of porewater was extracted for analysis. pH and DO were determined

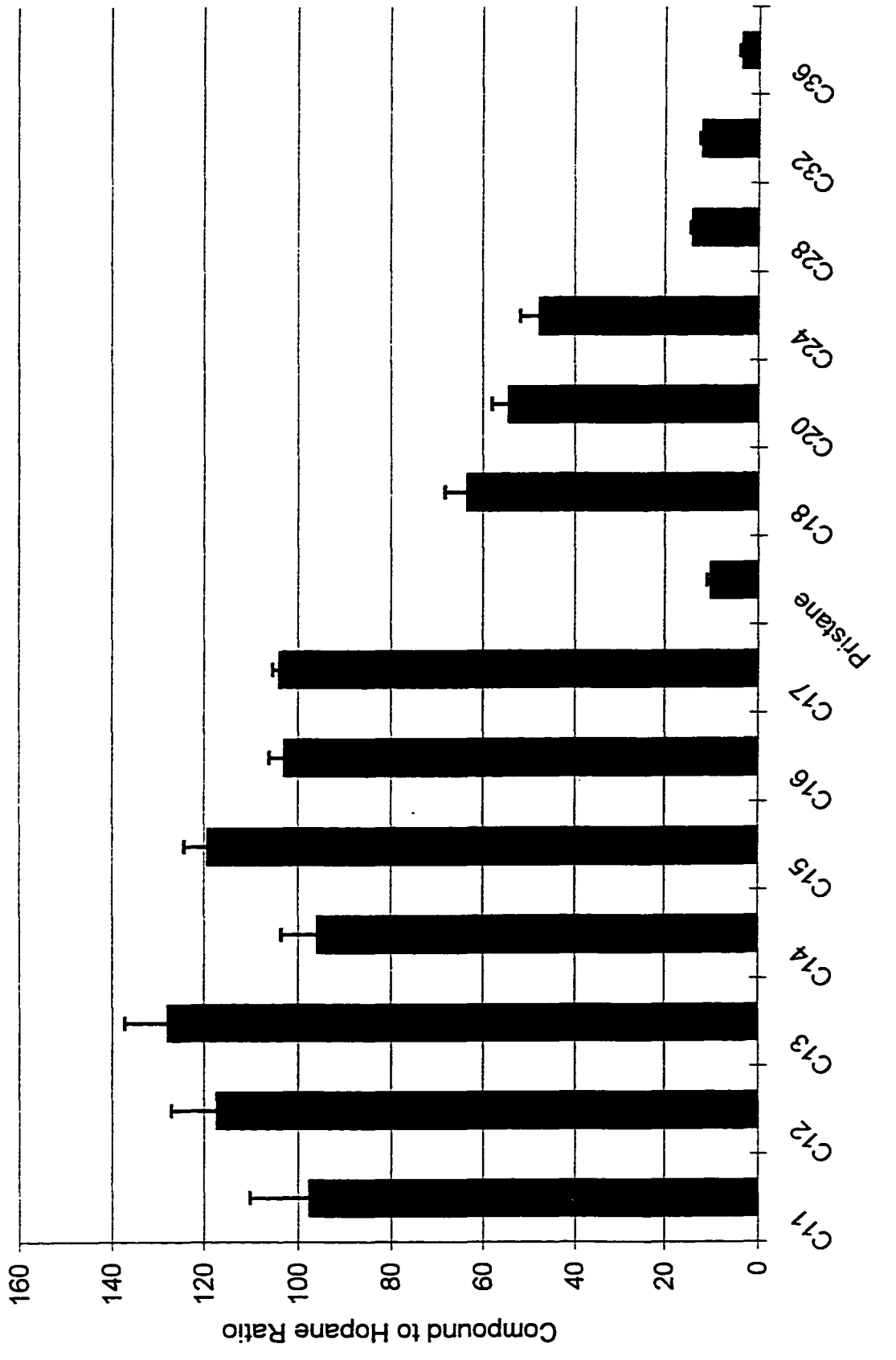

Figure 2.1 Initial Fingerprint of Oil Applied to Mesocosms

immediately after extraction by insertion of the appropriate electrical probe into a vial holding the sample. The samples were also analyzed for ammonia using an ammonia specific electrode which measured a millivolt value calibratable to a known ammonia concentration. Following analysis, the porewater was returned to the mesocosm from whence it came, except for about 2 ml lost in the ammonia analysis.

2.2.4.3 Measurement of Carbon Dioxide Evolution

Carbon dioxide is a product of microbial respiration. Accordingly, the evolution of carbon dioxide was monitored in the mesocosms to determine whether microbial activity was occurring and at what relative rate. In order to distinguish between microbial consumption of native organic matter and microbial consumption of applied oil, the applied oil was tagged with a radioactive carbon tracer, ^{14}C hexadecane. Scintillation counting of the evolved carbon dioxide could then be used to monitor oil biodegradation.

The CO_2 scavengers (NaOH traps) pneumatically downstream of each mesocosm consisted of a 100 ml test tube partially filled with a measured amount of 1 N NaOH. Air outflow from the mesocosms was sparged through the NaOH resulting in capture of the carbon dioxide. Observance of bubble flow rate in the scavenger tubes allowed verification of a constant and relatively uniform air supply. Approximately every 6 days the NaOH traps were changed. At each NaOH changeout the NaOH was scintillated to count the ^{14}C in it resulting from bioconversion of the ^{14}C tracer in the oil to ^{14}C in carbon dioxide and, thereby, monitor progress of biodegradation of the tracered hexadecane, and, presumably, biodegradation of the crude oil itself. Every second time the NaOH traps were changed, the NaOH was back-titrated to determine the total amount of carbon dioxide scavenged. Thus a carbon dioxide output rate could be calculated. While

the total carbon dioxide measurements do not distinguish between microbial degradation of marsh matter or crude oil, the scintillation results do indicate escape of the ^{14}C tracer applied to the oil in the air flow and subsequent capture in the NaOH trap.

Biodegradation of crude oil is conceptualized to behave similar to other microbial processes in a batch process scenario, that is, phases of activity include in order

- a lag phase when little consumption of substrate occurs,
- a period of rapid consumption of substrate, and
- a period of declining substrate consumption.

If plotted as amount of product produced during substrate consumption versus time, an S shaped curve would result with an inflection point between the lag phase and the period of rapid consumption and another inflection point between the period of rapid substrate consumption and the period of slowing consumption. Plots of cumulative ^{14}C evolved versus time were used to track this curve on a real time basis. When it was believed an inflection point had been reached, mesocosms were sacrificed. The actual sacrifices of the mesocosms took place at 43 days, 71 days, and 133 days after application of oil and nutrients.

2.3 Results and Discussion

2.3.1 Fraction of Oil Remaining

GC/MS analyses were done of extracts from the oiled marsh cores at various times to examine the degradation of the various oil components. The ratio of each compound to hopane (C/H ratio) was computed for three replicates from each mesocosm sacrificed. The average of these replicates was used as the mesocosm value and averaged with the other mesocosm of the same treatment sacrificed at this period to give the average ratio of the compound to hopane ratio

at this point in time to the compound to hopane ratio for the compound in the initial four cores. A standard deviation of the average compound to hopane ratio at the point in time to the initial compound to hopane ratio was also calculated using the two values.

The oil was extracted from the soil and the extract analyzed by GC/MS. The concentration of each of 14 indicator compounds was compared to the concentration of hopane which was used as a stable marker. Comparison of the oil was done using only the alkanes and hopane since none of the PAHs had concentrations in the extracted oil of over a few nanograms. Details of the extraction procedure are in Appendix A. A list of the compounds analyzed and details concerning the operation of the GC/MS are in Appendix D.

At 43 days, 71 days, and 133 days, two mesocosms of each treatment were sacrificed, the oil extracted, GC/MS analysis conducted, and the C/H ratio for each component summed across all components determined. Figures 2.2, 2.3, and 2.4 depict the results of the C/H ratio summed across all 14 compounds for each treatment at these intervals. The height of the bars may be seen to represent that portion of the total mass of oil initially present which is still remaining. Because the analysis is done using C/H ratio, that is, comparison to a non-biodegradable marker, the fraction remaining represents one minus the fraction biodegraded.

Examination of all three figures shows that the ultimate result is that all six treatments resulted in biodegradation of approximately 90 percent of the monitored components of the oil by 133 days.

Figures 2.2, 2.3, and 2.4 also show error bars representing one standard deviation. Because only two replicates of each treatment were analyzed at each

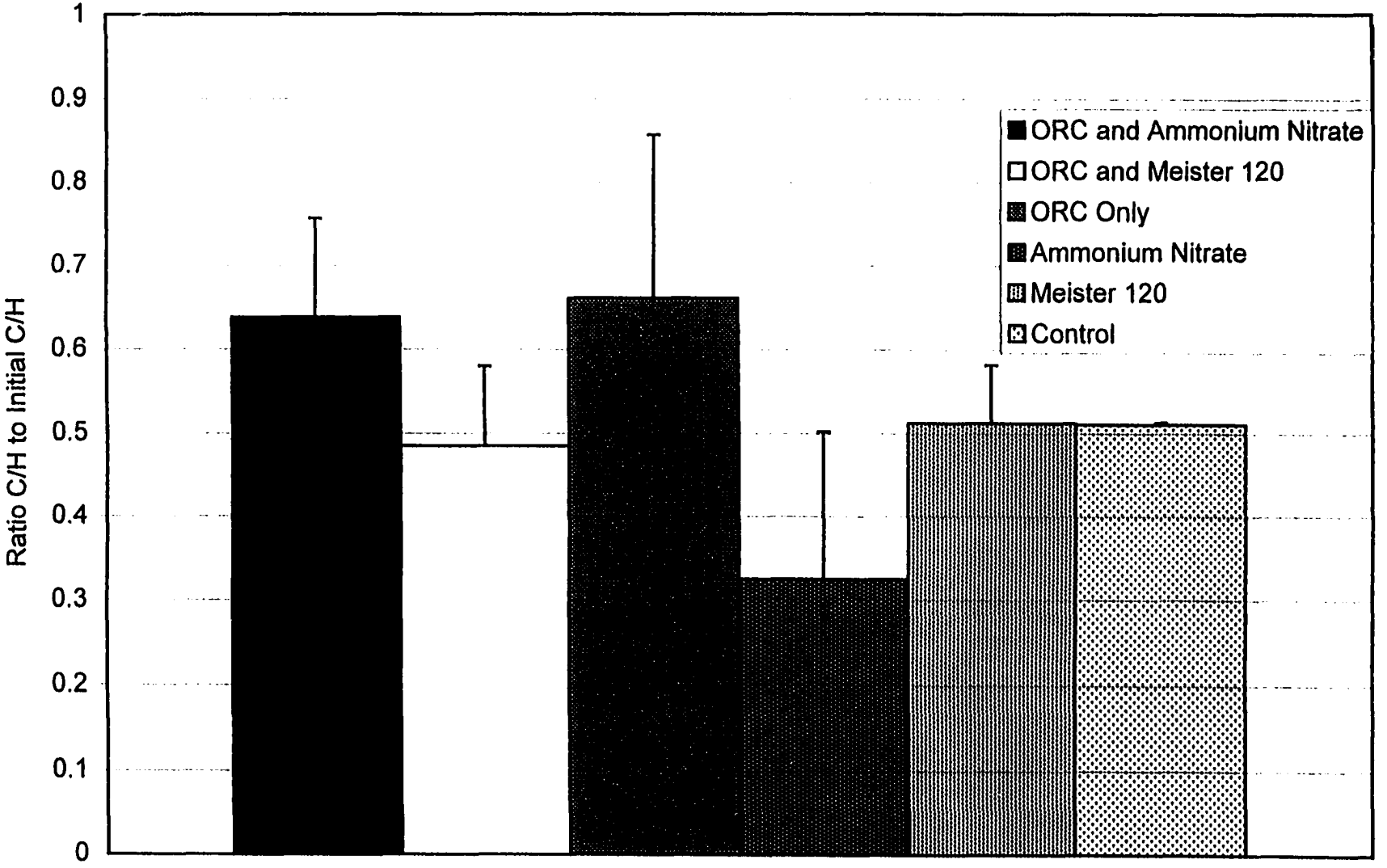

Figure 2.2 Fraction of Total Compounds to Hopane Ratio Remaining at 43 Days

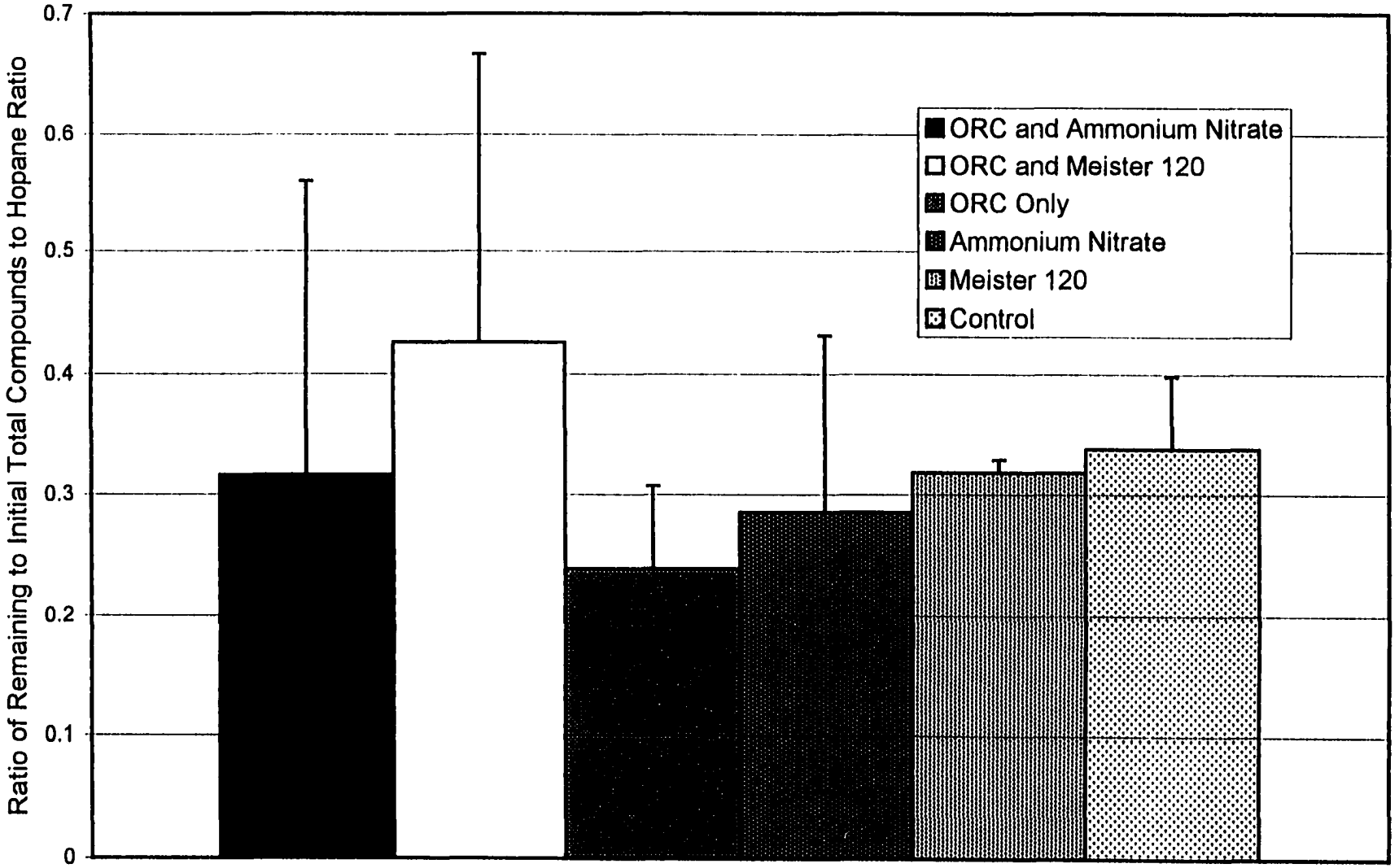

Figure 2.3 Fraction of Total Compounds to Hopane Ratio Remaining at 71 Days

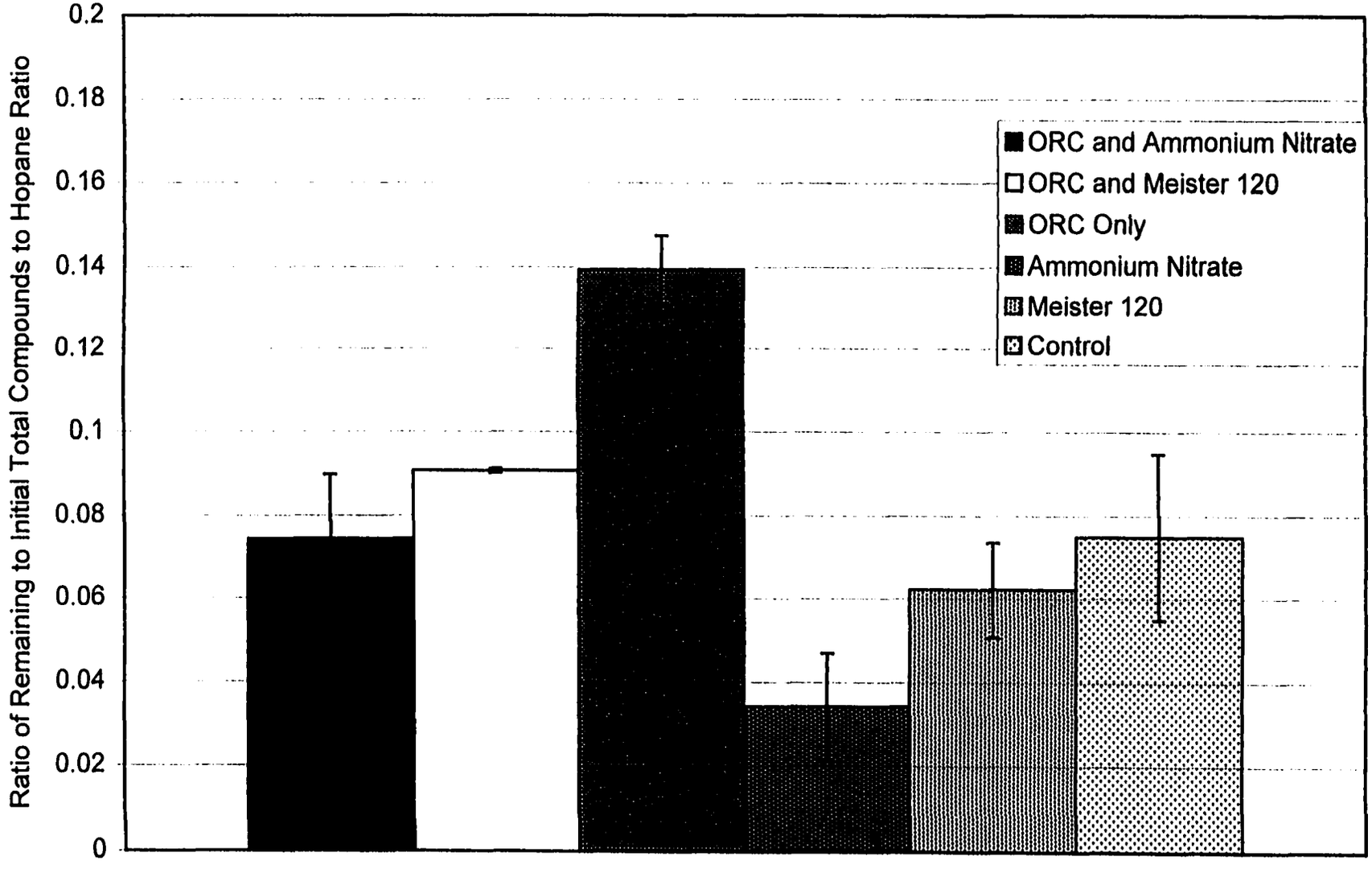

Figure 2.4 Fraction of Total Compounds to Hopane Ratio Remaining at 133 Days

time period the standard deviations in some cases are relatively large and one could justifiably argue about the significance of the relationship of the average performance of one treatment compared to another. Because of the setup of a mesocosm, extraction of oil to determine the C/H ratio involved sacrificing the mesocosm. As a result only two replicates could be sacrificed at each time interval, and a very limited number of time intervals could be used.

Figure 2.5 depicts the fraction of initial C/H ratio remaining at the start and at the three time intervals. Relative rates of biodegradation may be inferred from the average fraction remaining shown on this figure. The Student's t-test was used to test the significance of the difference in amount of oil remaining at the three extraction times, using the average and standard deviation (between the two mesocosms of a given treatment sacrificed at each interval). At the 0.05 significance level none of the treatments were better than the control at any of the extraction dates. At 0.10 significance the ammonium nitrate treatment had significantly less oil remaining than the control at 133 days. The kinetics of biodegradation were also examined. Linear and non-linear curve fitting using a variety of equations was done to best define the kinetics of the biodegradation. Attempts were made to determine rate constants, non-zero asymptotes, and possible lag times. First order decay [y=exp(-kt)] was finally chosen as the appropriate kinetic model based on goodness of fit and its usability as an engineering prediction tool. Appendix I has a discussion of the possible expressions of the decay of the oil and the advantages and disadvantages of the various expressions.

A first order rate constant for degradation of oil was determined for each treatment based on the average fraction remaining between the two mesocosms sacrificed. Because a mesocosm was destroyed to extract its oil, individual

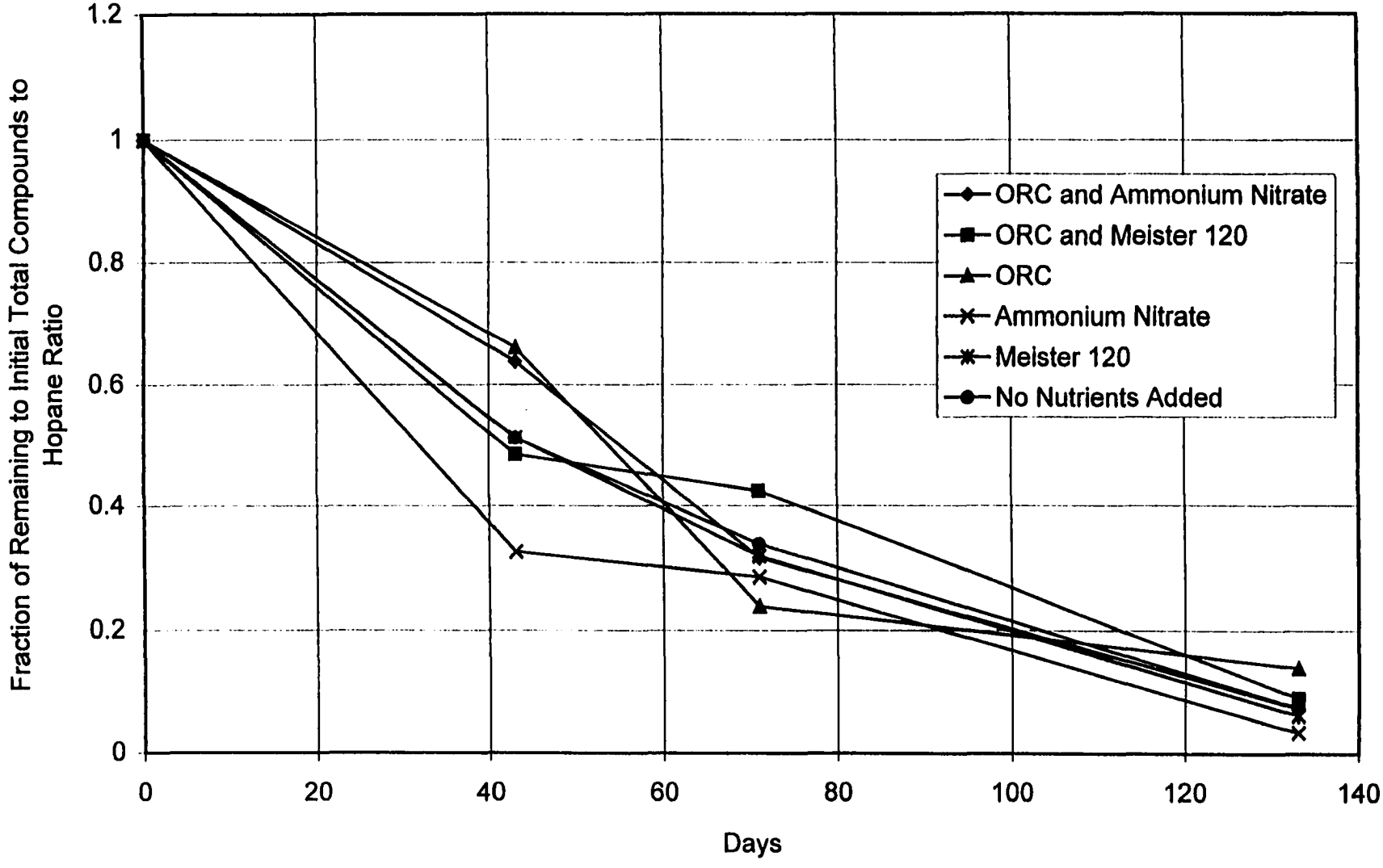

Figure 2.5 Fraction of Total Compounds to Hopane Ratio vs Time by Treatment

kinetics cannot be determined on a per mesocosm basis. Kinetics are based on the average of both mesocosms of a given treatment at each interval. Consequently the statistical significance of the rates determined cannot be established. Figure 2.6 presents the first order rate constants for the 13 n-alkanes measured, and also for the sum of these alkanes plus pristane. The rates can be compared to those in Table 1.1. The rates are similar to those of Jackson (1996) in his mesocosms, but less than half those experienced by Venosa et al (1996) in their beach plots.

While no statement can be made as to whether a given treatment is significantly (in the statistical sense) better than a control based on the rate parameters, the following observations are made of the degradation rates as presented:

- For 12 out of 13 of the compounds the mesocosms with ammonium nitrate but no ORC had faster rate parameters than the control.
- For 5 out of 13 of the compounds the mesocosms with Meister 120 but no ORC had faster rate parameters than the control.
- For 9 out of 13 of the compounds all three of the treatments which had ORC had rate parameters which were less than the control.

Based on this it appears that in the mesocosms, ammonium nitrate is beneficial to biodegradation, Meister is possibly better for some compounds, and ORC appears to be inhibitory. Based on these trends the decision was made to use ammonium nitrate and Meister but not ORC in the field plots.

Results of the compound to hopane ratio for the 14 individual compounds monitored at each time interval are contained in Appendix F.

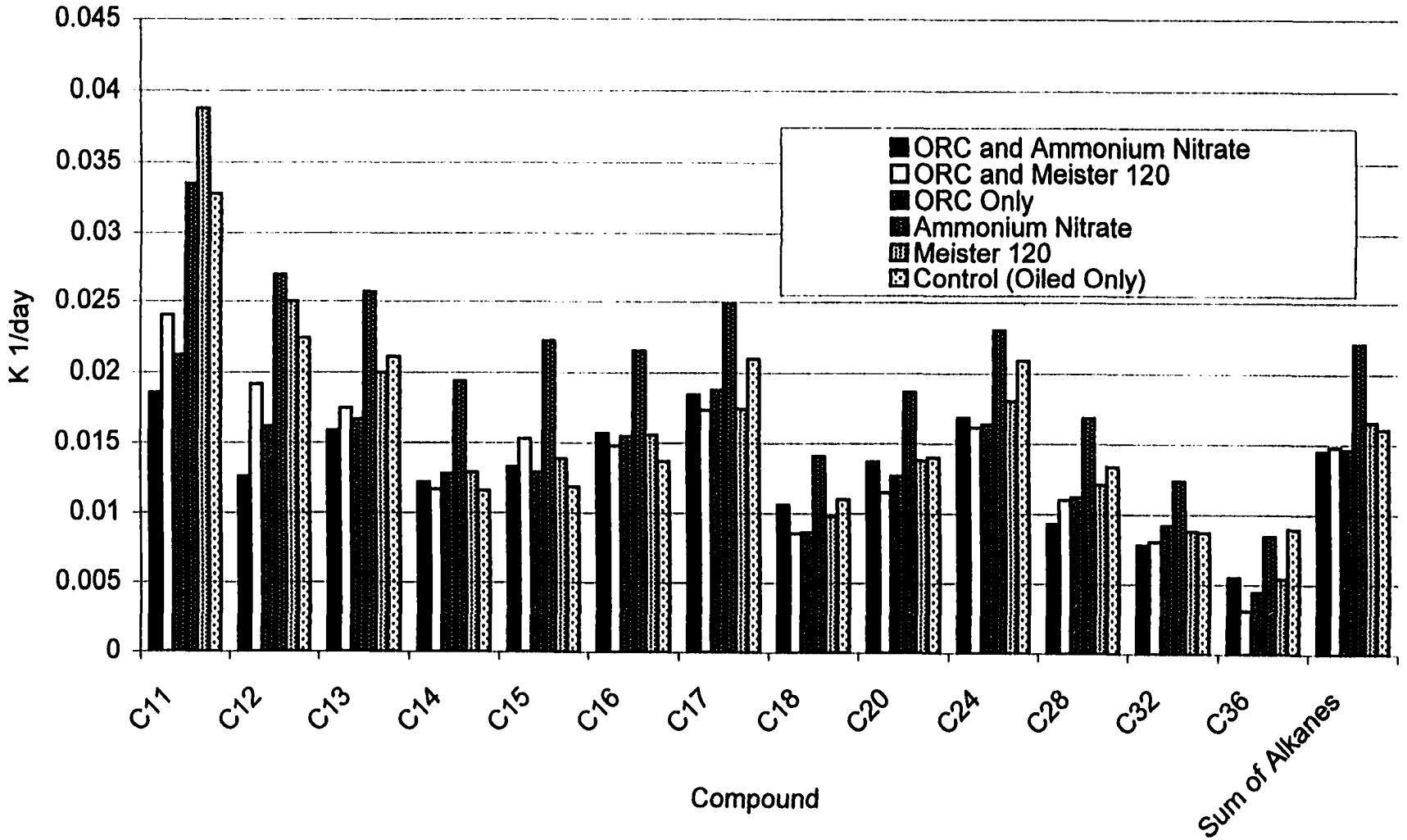

Figure 2.6 First Order Rate Parameter K by Treatment and Oil Component

2.3.2 Porewater Measurements

Figure 2.7 depicts the mesocosm porewater pH data. pH may be seen to lie in the range of 6 to 7.3 except for higher pH values for the mesocosms with both ORC and ammonium nitrate. While the pH values exhibited are not believed to be in a range inhibitory to microbial growth, it should be remembered that this treatment (ORC and ammonium nitrate) was the least successful in terms of evolution of radioactive CO_2 and of total CO_2. Figure 2.8 depicts the dissolved oxygen measurements. No trends between treatments or even between oiled and non-oiled mesocosms are noted. Two different DO meters were used. On a given day, however, all DO values were taken with a single DO meter. The apparent temporal variations are probably due to the use of the different DO meters.

The DO concentrations show the porewater to all be bordering on the anaerobic range. The method of obtaining the porewater sample should be remembered when interpreting DO values. A needle attached to syringe is inserted as shallowly as practical beneath the water surface in the mesocosm. Insufficient submergence of the needle resulted in a brief and small flow of water into the syringe followed by air. The needle would then be inserted slightly deeper. Realistically the porewater measured probably came from a few centimeters below the marsh surface, since extraction with a needle and syringe requires some head of fluid over the needle point to force the water into the low pressure area in the needle created by withdrawing the syringe plunger.

The DO measurements are not necessarily the maximum oxygen concentrations available anywhere in the oil impacted stratum. DO concentrations from porewater closer to the surface, but too shallow to effectively be extracted, may have greater values. The DO measurements imply that processes in the marsh are utilizing the oxygen. In the absence of oxygen consumption in the

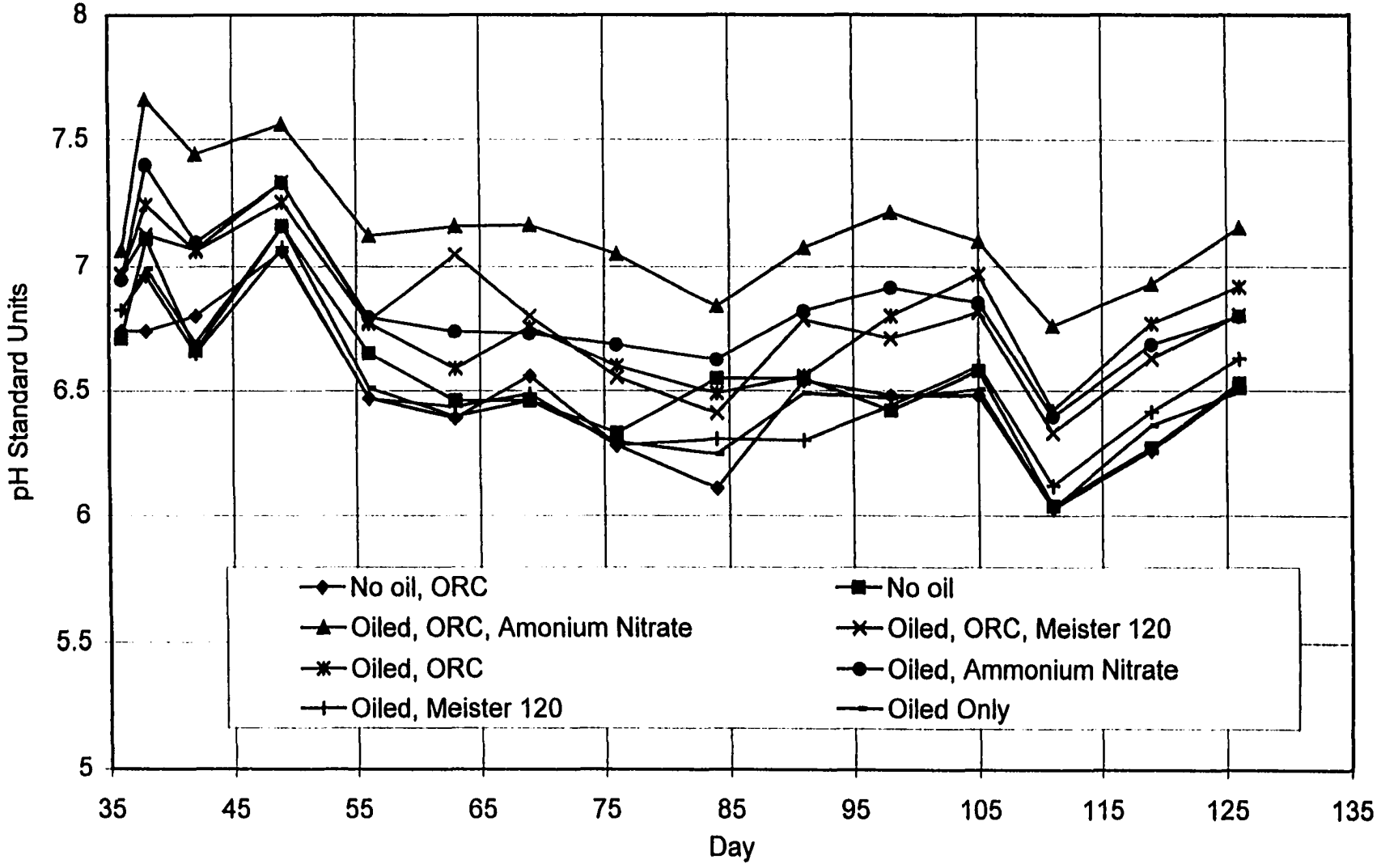

Figure 2.7 Mesocosm Porewater pH by Treatment

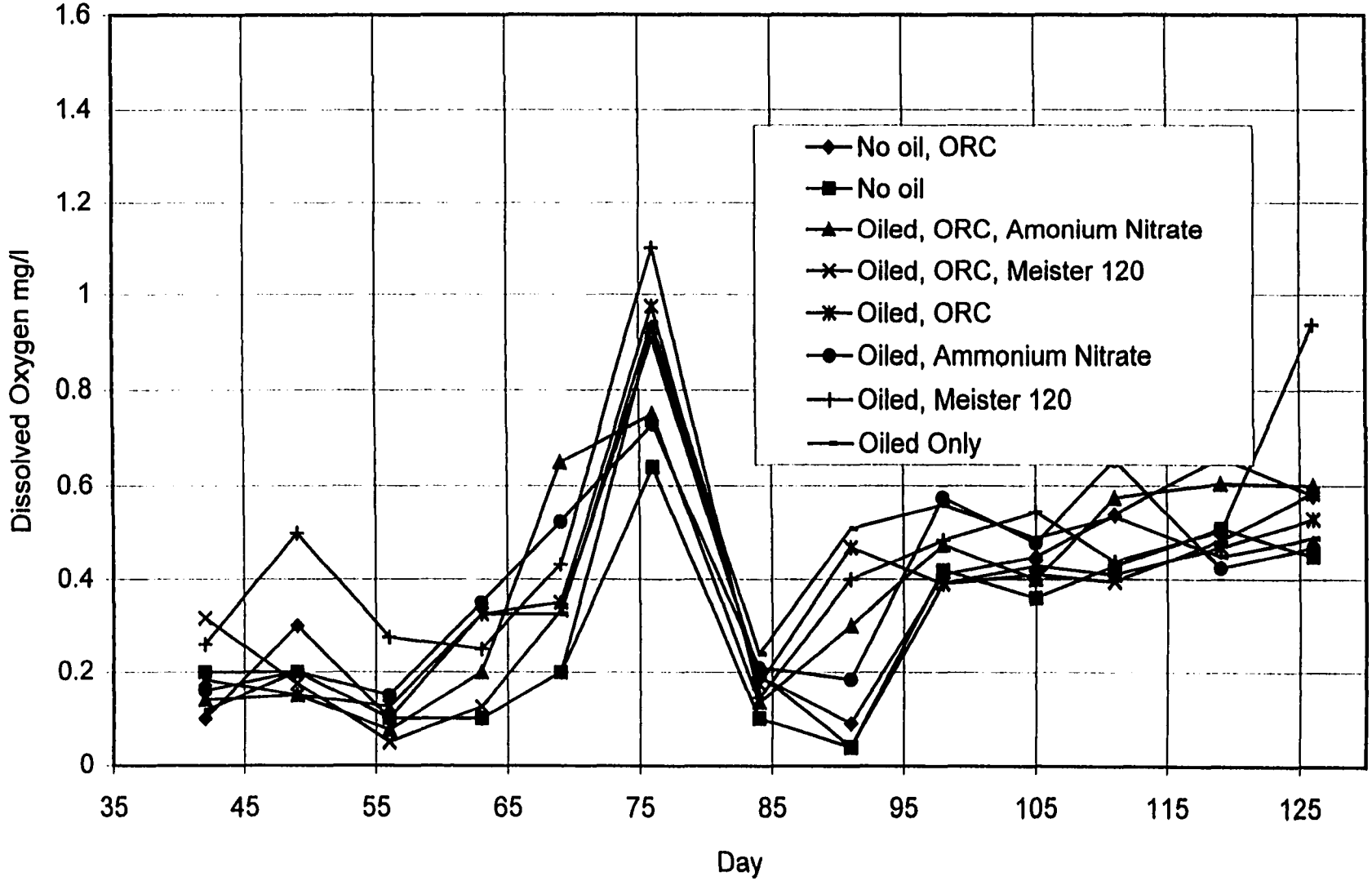

Figure 2.8 Mesocosm Porewater Dissolved Oxygen by Treatment

subsurface, an equilibrium oxygen concentration of 5 to 10 mg/l would have been expected.

Figure 2.9 depicts the concentrations of ammonia as N in the mesocosms. The ammonia in the porewater falls into three distinct classes. Those samples from the two treatments receiving ammonium nitrate generally have 60 to 120 mg/l of ammonia. Mesocosms receiving Meister time release urea have a lesser concentration of ammonia in the 20 to 60 mg/l range. Those mesocosms receiving oil but no nitrogen and the two mesocosms receiving neither oil nor nitrogen have concentrations of ammonia less than 20 mg/l, but generally above 5 mg/l. Temporal variations of ammonia are unclear, although the samples with ammonium nitrate appear to be declining with time.

It is interesting to note that ammonia in the concentration (50 mg/l) Jackson (1996) found beneficial in his radiorespirometry studies, or at the concentration considered optimal (30 mg/l) (Jackson, 1997) does not result in a highly effective nutrient condition in the mesocosms. The two treatments with the highest ammonia concentrations represent the best treatment (ammonium nitrate) and the worst treatment (ammonium nitrate and ORC) for degrading the oil as interpreted by the evolution of radiolabeled CO_2.

2.3.3 Carbon Dioxide Evolution

Figure 2.10 depicts the counts of ^{14}C as measured in the NaOH traps on the pneumatically downgradient side of each mesocosm. Graphs of the average cumulative counts per minute for each of the six treatments are shown. The cumulative counts of ^{14}C are normalized by dividing by the total 150,000 counts of ^{14}C added.

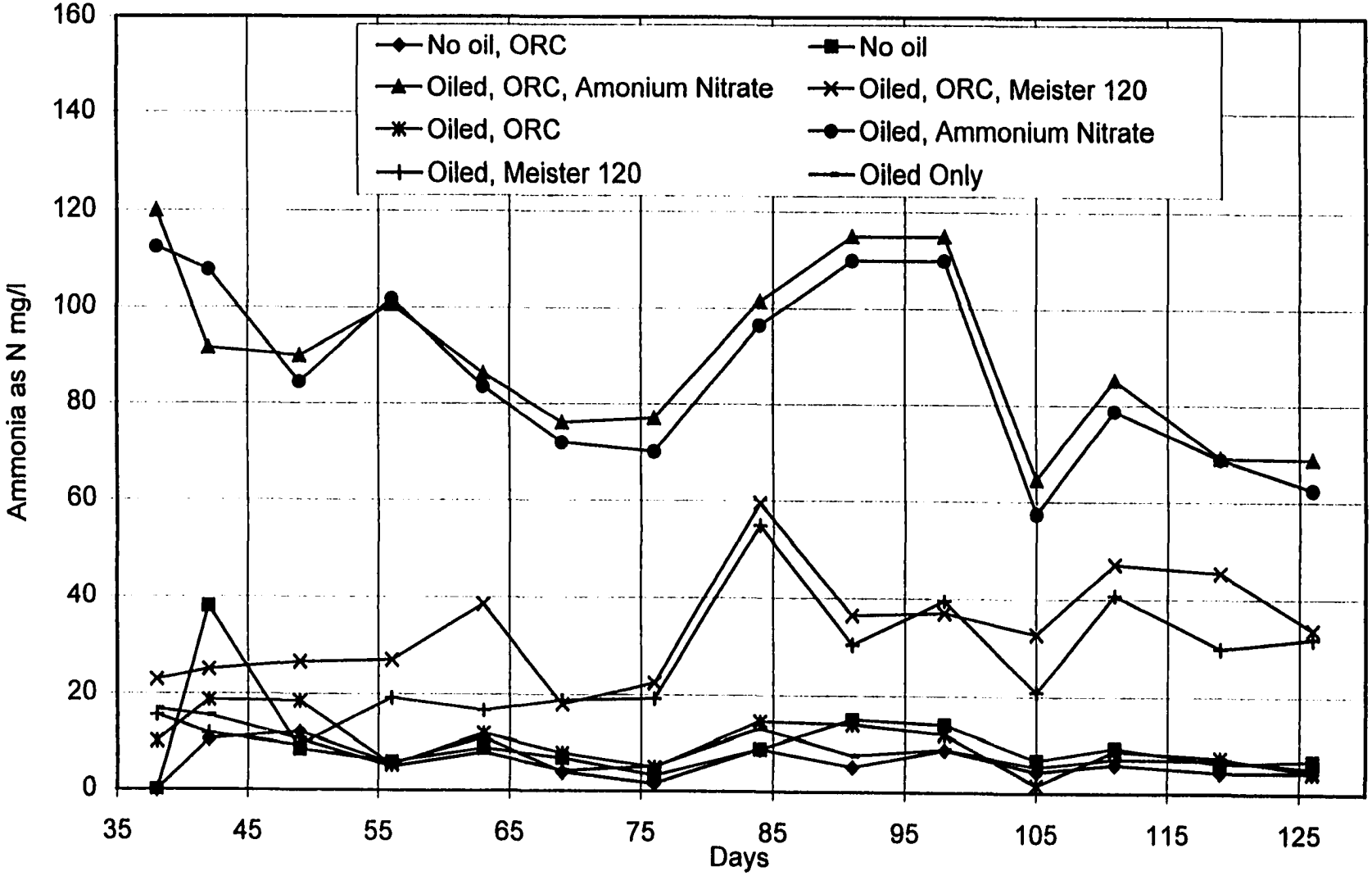

Figure 2.9 Mesocosm Porewater Ammonia by Treatment

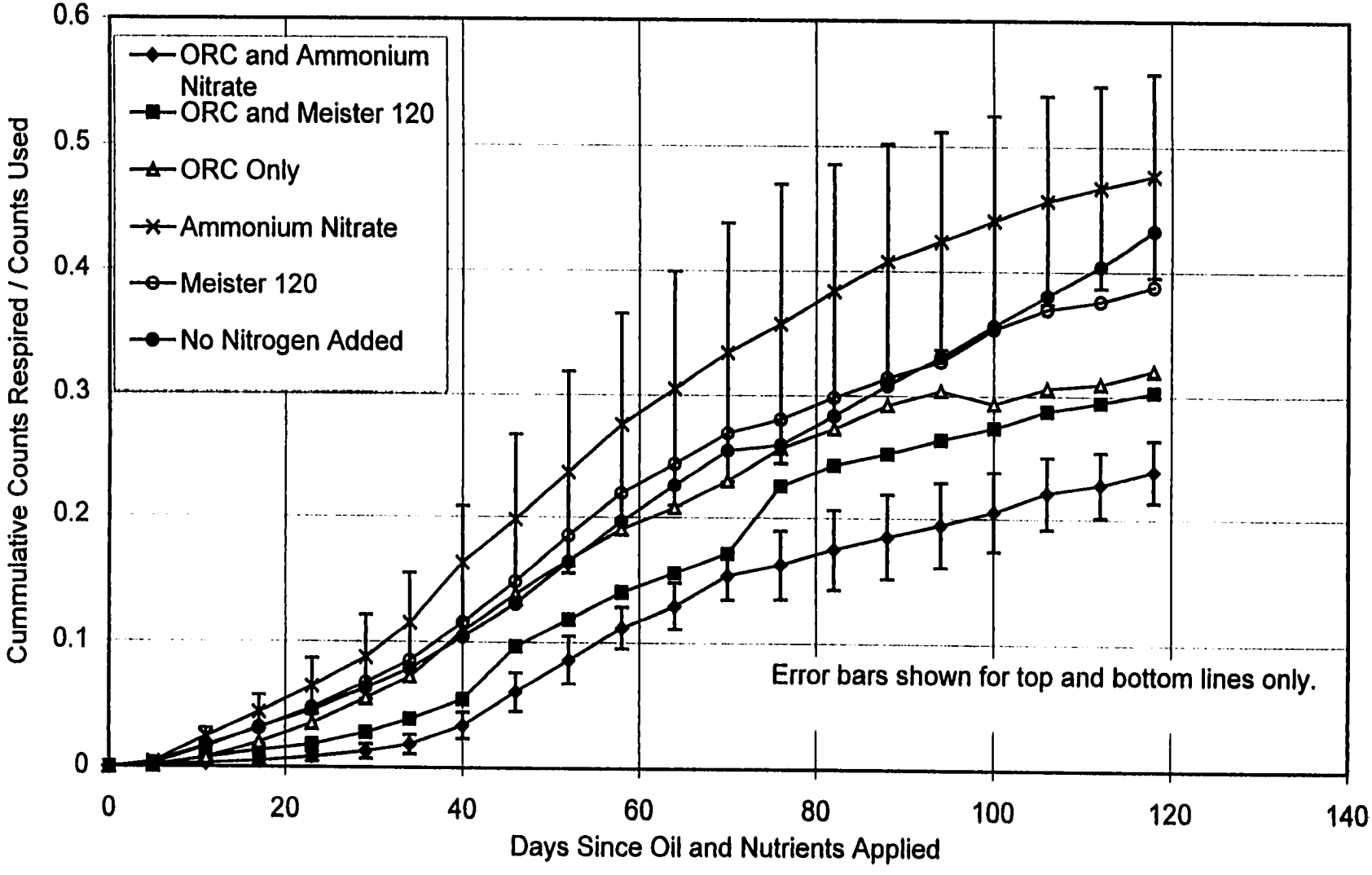

Figure 2.10 Mesocosm ^{14}C Respired vs Time

Error bars one standard deviation on either side of the average cumulative count for the best treatment (ammonium nitrate) and the worst treatment (ammonium nitrate and ORC) are shown. Error bars are not shown for treatment between these in efficacy since would result in numerous overlapping error bars and difficulty in interpretation. The width of the error band increased in time since initially six replicates of each treatment were monitored, but at day 43 and day 71 two of each treatment were sacrificed to extract the oil for GC/MS analysis. As a result of the fewer treatments after sacrifice the standard deviations increased. Occasionally a mesocosm was sacrificed earlier than planned if it leaked. This resulted in an earlier loss of replicates for the sacrificed treatment than for the others with consequential increase in standard deviation.

Examination of Figure 2.10 shows the treatment involving only the application of ammonium nitrate to be the most productive at evolution of radioactive carbon dioxide. The error bars show that considering a level of significance to be one standard deviation on either side of the average, the ammonium nitrate treatment is clearly superior to only the two treatments containing both ORC and nitrogen either as Meister 120 or as ammonium nitrate. The best treatment, is not, however, significantly (as interpreted by non-overlapping error bars) better than the remainder of the treatment.

A possible mass balance discrepancy may be seen from comparison of Figure 2.10 for ^{14}C respired to Figures 2.2, 2.3, and 2.4. Figure 2.4 implies that by the end of the mesocosm study approximately 90 percent of the oil had been biodegraded, while Figure 2.10 indicates, that even for the best treatments, only on the order of 40 to 50 percent of the radiolabeled tracer that had been added to the oil had been captured as CO_2. Since the radiotracer was hexadecane the amount of hexadecane remaining at the end (see Appendix F) was examined.

Two to 13 percent of the initial hexadecane remained, depending on the treatment, therefore 87 to 98 percent was degraded. Possible causes for this difference in the amount of degradation as measured by the different methods could include, from the most likely to the least likely;

- During biodegradation there occurred conversion of oil compounds from a compound selected for analysis in the GC/MS to a compound not selected for analysis. This conversion rather than mineralization to CO_2 would be interpreted as biodegradation by GC/MS analysis but would not have resulted in release of ^{14}C.
- Less than complete capture of all the ^{14}C respired in the NaOH trap.
- A portion of the mesocosm oil being deeper than the 5 cm top portion used in analysis of the oil. This deeper oil would have been less in contact with adequate oxygen and might have had a lesser degree of biodegradation than the near surface oil, with the result this deeper ^{14}C was less completely mineralized.
- An error in the calculation of the initial radiocarbon dose applied.

A combination of the first two scenarios is likely. In aerobic metabolism most of the carbon in the oil would be converted to CO_2, however, some portion would be converted to microbe cell mass. In the mesocosms this percentage of the carbon is expected to be small based on mass balances using the method developed by McCarty (Sawyer et al, 1994) which uses stoichiometry with an empirical formula for biomass to account for electron acceptors, electron donors, and elements used in cell synthesis.

In an anaerobic environment, as probably existed within a few centimeters below the mesocosm surface, degradation of some oil components can also take place by sulfate reduction or methanogenesis, with the carbon in the hydrocarbon

being mineralized to either carbonate, or to a combination of methane and carbon dioxide (Borden, 1994). Caldwell et al (1998) found that n-alkanes in the C_{15} to C_{34} range were capable of being mineralized under sulfate reducing conditions. If the oil were transformed into simpler compounds amenable to methanogenesis, then a degradation of these compounds would have evolved methane in addition to carbon dioxide. The methane would have been poorly captured in the NaOH traps and, therefore, its ^{14}C would not have shown up in the scintillation counts.

Whatever the cause of the apparent mass balance discrepancy, it does not affect the validity of comparison between treatments since all had the same oil applied, the same NaOH trap arrangement, and the same extraction procedure. It should also be remembered that the primary purpose of the ^{14}C scintillation was to monitor the growth curve to determine the inflection points at which to conduct GC/MS analyses.

The ^{14}C respiration curves for each treatment were fitted to various curve fitting equations. The equation used consisted of first order with the possibility of lag times or asymptotes at less than full recovery of the radiolabels. Table 2.2 shows the rate parameters for the various treatments using a first order equation with a lag time [y=1-exp(-k(t-b))]. The rate parameters for the sum of the alkanes are also presented here. Once again the discrepancy between the oil degraded and the radio tracers recovered can be seen. It may be noted that the rates of evolution of the radio tracer are only about one-third of the rate of degradation of the oil.

Based upon the value of k from the ^{14}C scintillation, the ammonium nitrate treatment showed the most rapid mineralization. All the treatments showed from 7 to 14 days lag time before respiration of the radiolabel began in earnest. The

Table 2.2 Rate Parameters for Average ^{14}C Mineralization and Oil Biodegradation As Determined from Mesocosm Studies

Treatment	^{14}C Mineralization k 1/day	^{14}C Mineralization C-days	Oil Biodegradation k 1/day
ORC and Ammonium Nitrate	0.0026	14.0	0.0145
ORC and Meister 120	0.0035	12.5	0.0148
ORC Only	0.0039	7.6	0.0146
Ammonium Nitrate	0.0062	7.5	0.0221
Meister 120	0.0046	7.9	0.0166
Control (Oiled Only)	0.0048	10.0	0.0161

Table 2.3 Rate Parameters for Average Carbon Dioxide Respiration in Mesocosm Studies

Treatment	mg/day	b-days
No Oil, ORC	73.1	-159
No OIL, No Nutrients	83.8	-407
ORC and Ammonium Nitrate	60.600	-483
ORC and Meister 120	66.300	-532
ORC Only	75.400	-590
Ammonium Nitrate	97.600	-726
Meister 120	84.100	-256
Control (Oiled Only)	83.900	-311

treatments without ORC all have a more rapid degradation rate than those with ORC, exhibiting the inhibitory effect experienced with the oil and the ORC.

Figure 2.11 depicts the cumulative output of carbon dioxide from each of the treatments plus the two non-oiled mesocosms. As with the output of radiolabeled carbon dioxide, the oiled treatment with ammonium nitrate evolves the most carbon dioxide and the oiled treatment with ORC and ammonium nitrate evolves the least carbon dioxide. The four treatments without ORC all evolve more carbon dioxide than the four treatments with ORC, however the performance of many of the treatments was very similar. Error bars one standard deviation above and below the average have been added to the most productive treatment in terms of total carbon dioxide evolved and the least productive treatment. It may be seen that the error bars for these two treatments nearly touch even for recent data. Once again, the best treatment is seen to not be significantly (as indicated by non overlapping error bars) better than the control of no nitrogen or ORC added.

A straight line [y=mx+b] was fitted to the carbon dioxide data from Figure 2.11. The y intercept, b, is not believed to have any physical significance, but is caused by the nonlinearly of the initial data. The slope of the line, m, represents the milligrams of CO_2 evolved per day for the treatment. A higher m indicates a treatment which is evolving more CO_2. The treatment perceived best based on ^{14}C, ammonium nitrate, is seen to be respiring the most CO_2. The least effective treatment based on ^{14}C, is also seen to be respiring the least CO_2. Table 2.3 presents the parameters summarized for the treatments both oiled and nonoiled.

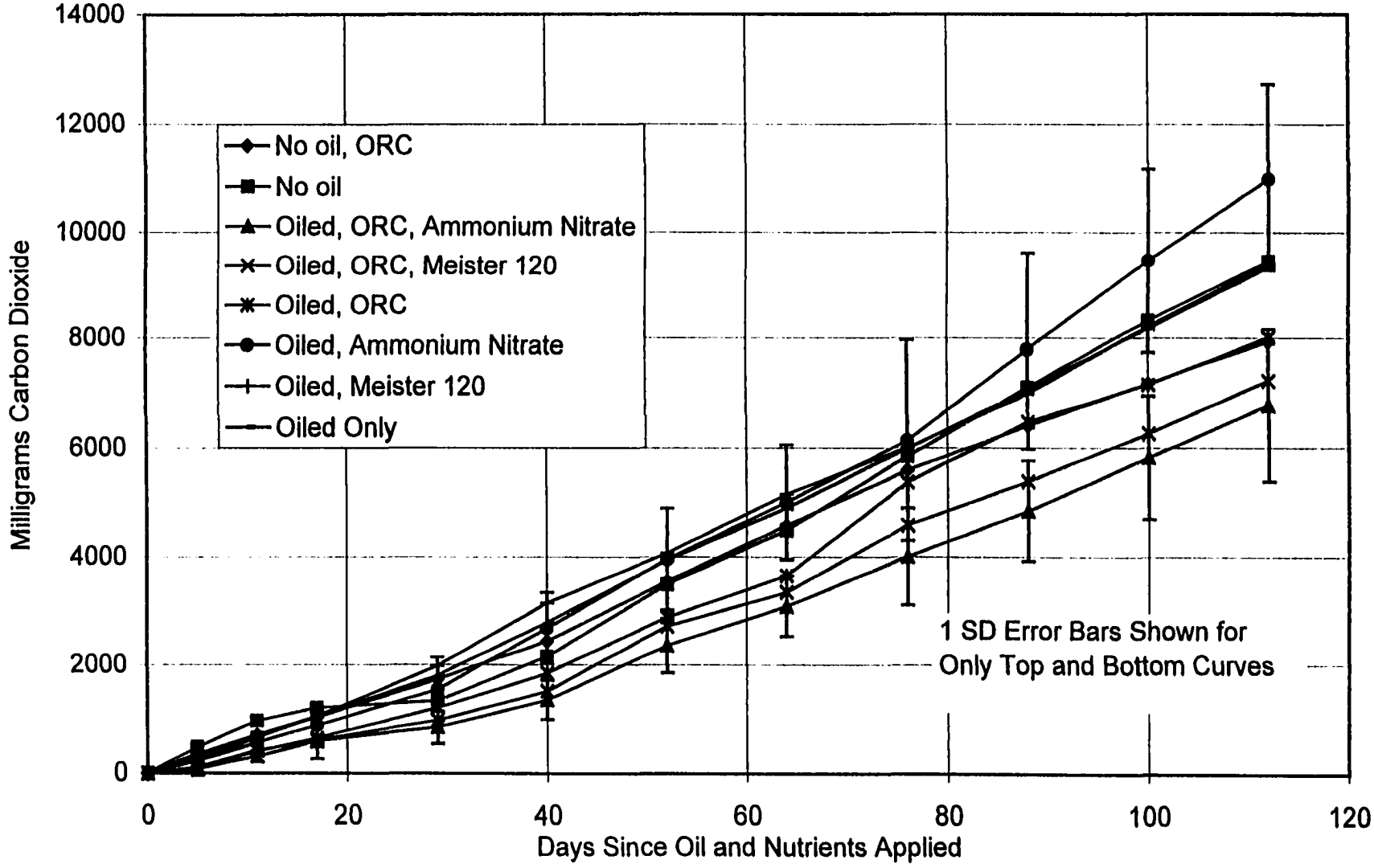

Figure 2.11 Mesocosm Carbon Dioxide Respired vs Time

2.4 Conclusions

2.4.1 Efficacy of Nitrogen Addition

While all treatment resulted in substantial biodegradation of the crude oil, it may been seen that this biodegradation occurred fastest with ammonium nitrate. The carbon dioxide respiration studies show ammonium nitrate to be superior to the control but not significantly so as interpreted by the overlapping one standard deviation error bars. The GC/MS data for the sum of the alkanes indicate that ammonium nitrate is not superior to the control at 0.05 significance but is at 0.10 significance.

Examination of the kinetic rate parameters from the mesocosm data, while not having replicates which allowed significance testing, indicated that ammonium nitrate in most cases resulted in more rapid degradation of the oil compounds than in the control.

2.4.2 Non-efficacy of Oxygen Release Compound

The application of the oxygen release compound, ORC, showed no promise in this application, in fact, it appears that biodegradation was inhibited in the mesocosms in which it was used.

2.4.3 Implication for Field Phase of Research

Based on the likely benefits of ammonium nitrate, as demonstrated from the mesocosms, it was decided to use ammonium nitrate as one of the treatments in the field plots for the next phase of the research. Based on the apparent lack of benefit from ORC, and the expense of ORC, it was decided not to apply ORC in the field plots.

The mesocosms were recognized to represent a closed environment with respect to the escape of nitrogen except in gaseous form. In the field, however, tidal flux is expected to flush out soluble nutrients. For this reason, despite its

relative lack of promise in the mesocosms, it was decided to include a time release nitrogen formulation in the field plots.

3. Field Tests of Nutrient Formulations

3.1 Introduction

The hypothesis in this phase was that, in the field plots, a given nutrient application would result in oil biodegradation significantly faster than biodegradation of the oil when no nutrients were applied.

Accordingly, the primary objective was to collect data sufficient to prove or disprove this hypothesis. This data would consist of oil samples to be analyzed and the degree of biodegradation measured versus time. If the hypothesis were proved true, it was also intended to define conditions which optimized the biodegradation. A second objective was, therefore, to collect that data, which would allow one in the field, on a near real-time basis to determine and economically maintain optimum nitrogen concentrations for biodegradation. This would involve:

- confirmation that selected nutrient application rates resulted in significantly better biodegradation than in the control,
- determination of whether nitrogen applications persisted in the field or were ephemeral, and
- determination of the nutrient application frequency to maintain optimum concentrations for oil degradation.

To achieve these objectives a field study was designed using four plot types:

- no treatment
- oiled
- oiled with ammonium nitrate
- oiled with a time release nitrogen fertilizer

Dimensions of 6 foot by 6 foot were selected as the size of each plot since this was the maximum size over which each portion of the interior of the plot could be reached by hand without setting foot into the plot interior. The maximum feasible size plots were used since Alexander and Webb (1987) had expressed belief that close access to oil free areas nearby may have affected the performance of smaller oiled plots used by others.

The statistical strength of the conclusions of the research depend on the number of replicate plots and the variability in behavior between the plots of a given treatment. The variability which would be observed between plots was unknown prior to the start of the research, therefore, no rational selection of the number of replicate plots could be made. It was suspected that a salt marsh would present greater variability than Venosa et al (1996) had experienced five replicates in a beach plot study. Ten replicates were, therefore, used. The ten replicates times the four treatments or control were the maximum attainable within the constraints of time, budget, and the conditions of the permit that had been obtained from the regulatory agency to conduct the work in a wetland.

3.2 Materials and Methods

3.2.1 Marsh Description

The marsh used for the field plots is located in Pointe au Chien Wildlife Management Area southeast of Montegut, Terrebonne Parish, Louisiana (see Figure 3.1). The marsh is adjacent to the left descending bank natural levee of a northwest/southeast trending former distributary channel. The marsh is a salt marsh with the predominant vegetation being *S. Alterniflora*. The location of the plots is approximately 50 to 100 meters northeast of the upland edge of the salt marsh. Approximately 20 meters further northeast the marsh turns to open water. Southwest of the marsh lies the natural levee of a former Mississippi River

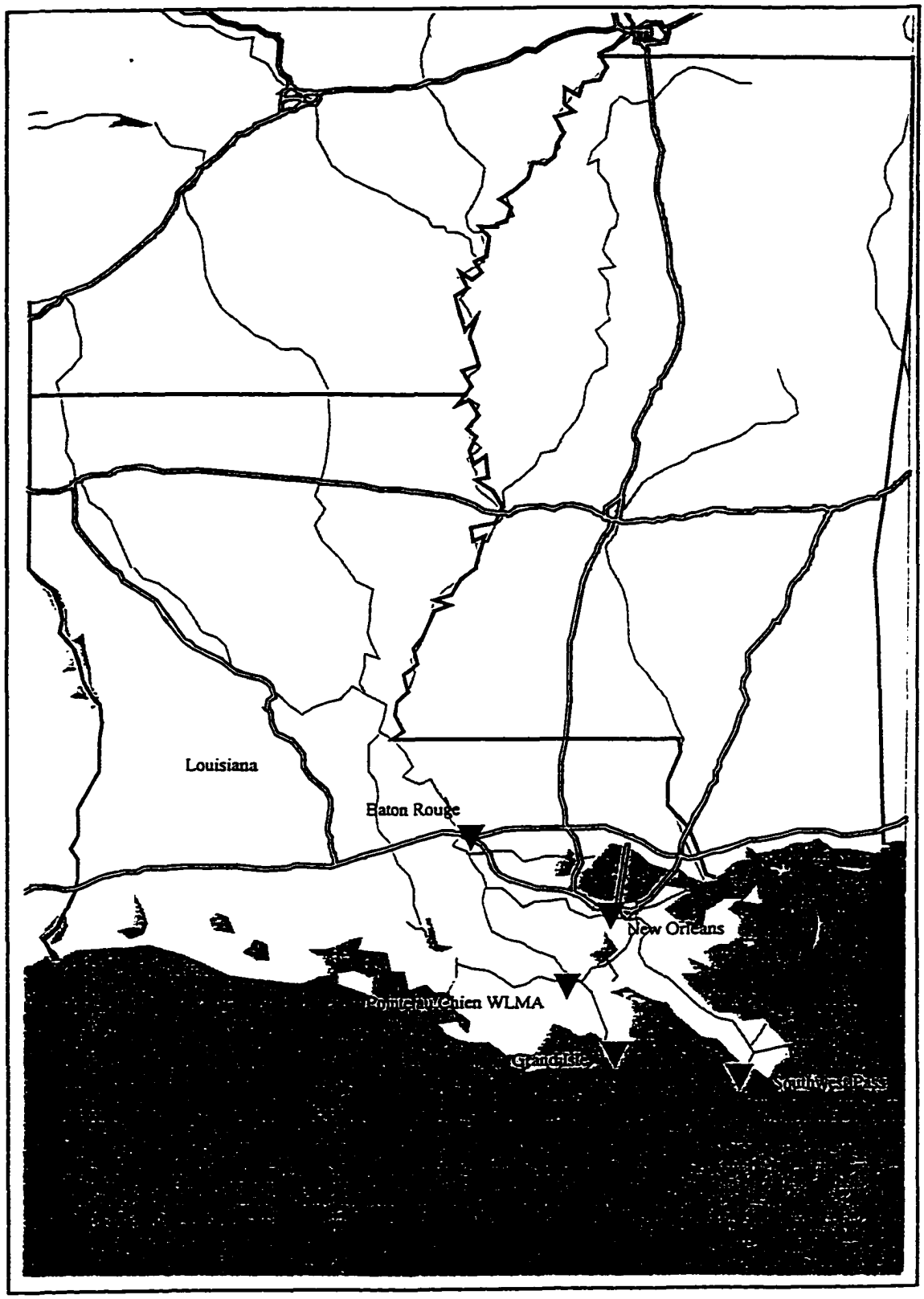

Figure 3.1 Vicinity Map

subdistributary, Bayou Jean Charles. The demarcation between marsh and nonwetland has been established by creation of a fastland of the higher ground along Bayou Jean Charles's natural levee. Near the toe of the natural levee, as one proceeds northeastward toward the marsh lies a drainage ditch followed on the northeast by a continuous spoil bank which hydrologically isolates the marsh from the fastland. The presence of dead trees standing in the marsh within a few hundred meters, and the occasional firmer footing presumably consisting of fallen, but undecayed trees, yield evidence that the marsh was formerly a swamp.

Tidal variations as informally observed in the marsh were fractions of a foot. Tidal predictions at a tide station located several miles away also show variation on the order of 0.3 to 0.4 foot over a day and about 1 foot over the entire course of the study (Figures 3.2 and 3.3).

3.2.2 Calculation of Nutrient and Oil Application Rates

Ten replicates each of the four different plot types were established. The plot types were:

- No treatment - this setup allowed measurement of spatial and temporal variations and variability in porewater parameters
- Oiled only - this setup provided the control. The efficacy of the other treatments were measured against this.
- Oiled with ammonium nitrate - 6 mg N/ square cm of marsh was applied, to provide 3 mg N/ square cm in the ammonium ion plus 3 mg N/ square cm as nitrate.
- Oiled with Meister time release urea. This was similar to a treatment used in the mesocosm except that 70 day release rather than 120 day release fertilizer was used. The application rate provided 3 mg-N/square cm.

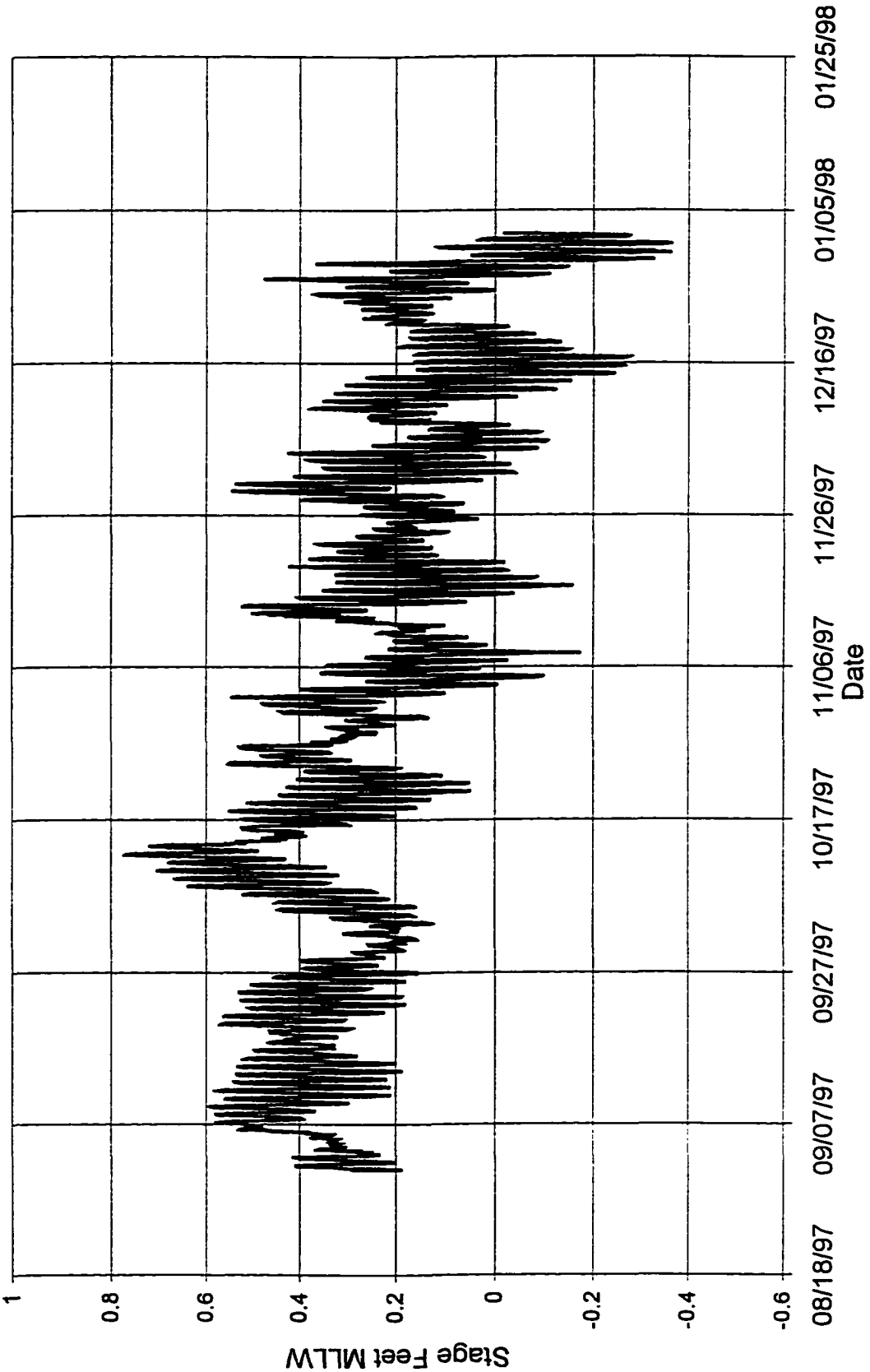

Figure 3.2 Tidal Record Grand Isle, Louisiana Late 1997

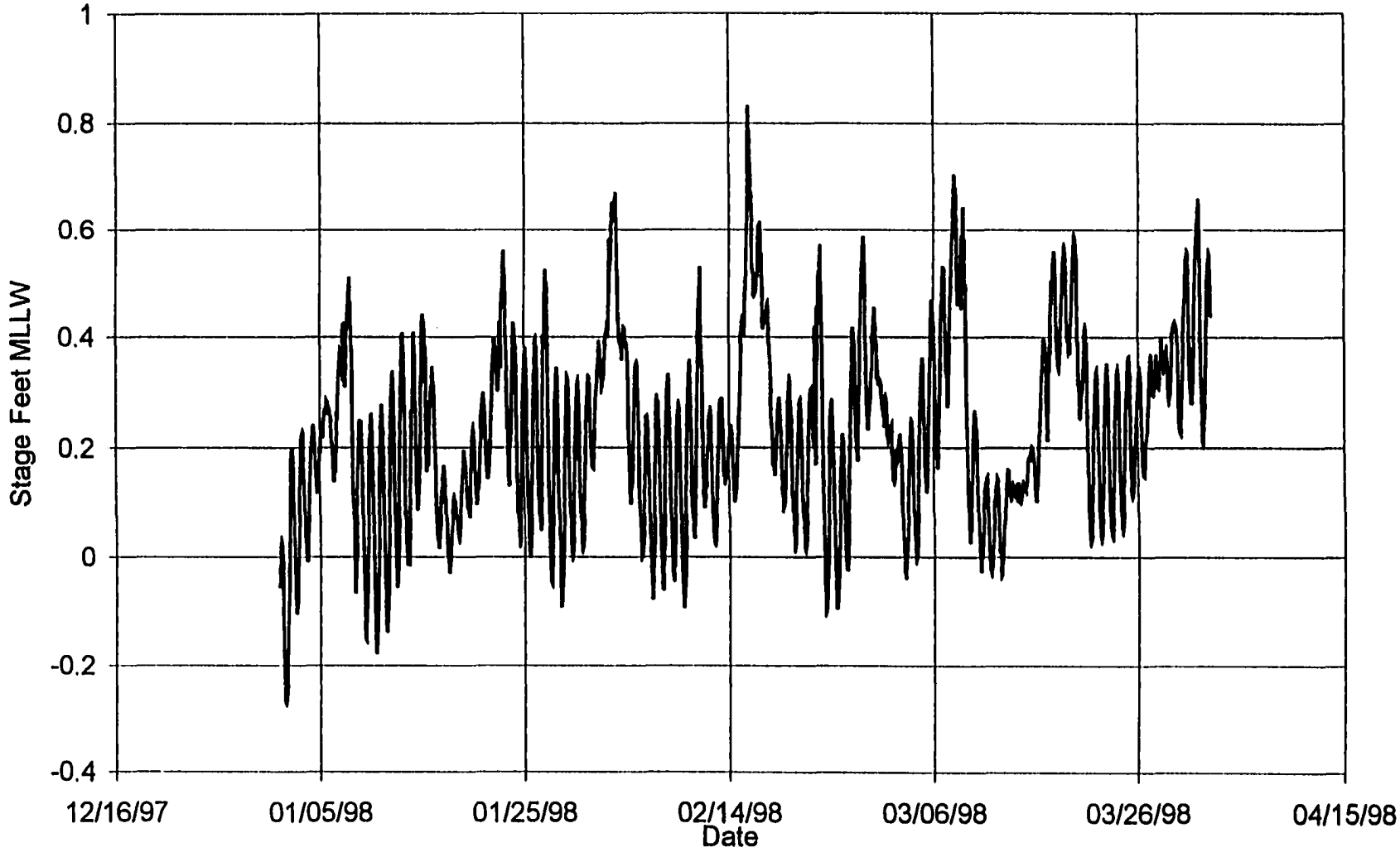

Figure 3.3 Tidal Record Grand Isle, Louisiana Early 1998

The crude oil used in the experiments was sweet Louisiana crude with a specific gravity of 0.82. This is a sweet oil, high in alkanes and low in polyaromatic hydrocarbons (PAHs).

The sweet Louisiana crude oil was obtained from Placid Oil Company. Approximately 37.5 gallons were used. Prior to application the oil was artificially weathered to remove some of the more volatile compounds and mimic the loss of volatiles expected while an oil spill drifted in open water. Weathering was accomplished by sparging one 90 cubic foot bottle of class D breathing air through it over an approximately 2 hour period. Sparging of the oil to simulate weathering prior to application resulted in minimal loss of volume.

While both the oil used in the mesocosm studies and the oil used in the field plots were sweet Louisiana crude, they were obtained from different sources approximately a year apart. The artificial weathering technique used on the small volume used in the mesocosms was also different from the larger volume used in the field plots. Therefore, while the behavior of biodegradation is expected to be similar between the two oil, the ratio of compounds in the initial fingerprint differs.

Oil was applied to the field plots at the rate of 1.16 kg/m^2 (1.41 $liters/m^2$) in a single application. For a 6 foot by 6 foot plot, this translates to 3880 grams, or with an SG of 0.82, 4.73 liters. This application rate was selected based on past work at L.S.U. by Jackson (1996). By comparison, Venosa applied oil in a beach experiment (Venosa et al, 1996) at 3.78 liters per square meter or 3.2 kg/m^2 based on the oil having a specific gravity of 0.848.

Research by Jackson (1996, 1997) found that degradation of oil was maximized when nitrogen in the porewater was in the 30 to 50 mg/l NH_3-N range. Jackson (1997) found that an application rate of 3 mg /square cm ammonium as

N resulted in the desired porewater concentration. The nitrogen application was, therefore, made at 3 mg/sq cm of marsh.

Meister 70 day release coated urea was obtained from Helena Chemical in Tampa, Florida. The anticipated cost of the material in a full scale field application is $1300 to $1400 per ton. The 120 day release formulation of Meister had been used in the mesocosm studies. Because of the rapid biodegradation in the mesocosms, a more rapid release formulation was chosen for the field plots. For the coated urea, the 3 mg N/square cm application rate translated into 250.8 grams of fertilizer per 6 foot square plot.

The other ammonia N source was ammonium nitrate. Ammonium nitrate was purchased from a local farm supply store at a price of about $7 for a 50 pound bag. An application of 6 mg N per square cm was used to achieve 3 mg N/square cm as ammonium. As a result an additional 3 mg N/square cm as nitrate was also attained. A 6 mg N/square cm application rate translates to 573.3 grams of fertilizer per 6 foot square plot.

3.2.3 Construction of Field Plots

The field plots were located in a salt marsh, populated with *Spartina alterniflora*, at Pointe au Chien Wildlife Management Area. This marsh is just south of previous areas used in research by other researchers from L.S.U., and therefore a relationship had already been developed with the property owner. Marsh cores for the mesocosms were obtained from the same area.

Forty plots were constructed in ten blocks of four plots each, thereby resulting in ten replicates for each treatment. Each plot in the block had one of the four treatments applied. Which plot in each block received which treatment was determined randomly to prevent systematic bias from position effects. Plots in a block were separated by 6 feet except in block D where the spacing was 12 feet.

Blocks were generally set at least 6 feet from the edge of the neighboring block, but the block location was adjusted slightly to find an area where all plots in the block had relatively uniform conditions. The plots were delimited with four 6-foot long stakes supporting a silt fence around the perimeter of the plot. An oil absorbent boom was placed on the waterward side of the experimental area. Figures 3.4 and 3.5 are schematics of the block and plot layout.

The oil for each plot which was oiled was measured into a pneumatic spray bottle and sprayed onto the ground in the plot. Care was taken to spray onto the marsh surface at the base of the vegetation rather than spraying the upper portion of the vegetation itself, since application in this manner approximated arrival of oil floating on the incoming tide. Smith et al (1984) and Mendelssohn et al (1990) indicated that damage to *S. alterniflora* is usually not severe unless the tidal range causes the oil to contact the vegetative canopy.

The Meister coated urea and the ammonium nitrate were preweighed and containerized for each plot prior to transit to the field. In the field the fertilizer was sprinkled evenly from a gloved hand onto the plot.

3.2.4 Monitoring

Measurement of biodegradation and the changes in environmental parameters associated with the biodegradation was by means of analysis of the concentrations of oil itself, marsh porewater analyses for nitrate and ammonia, extractable ammonia from marsh sediments, and counts of microbes in marsh soils. These measurements were made every 3 to 6 weeks. A timeline of activities during the field phase of the research is in Table 3.1.

3.2.4.1 Crude Oil

Soil samples were taken from each oiled plot every 3 to 6 weeks. Soil was removed from four randomly determined locations in each plot during each sampling

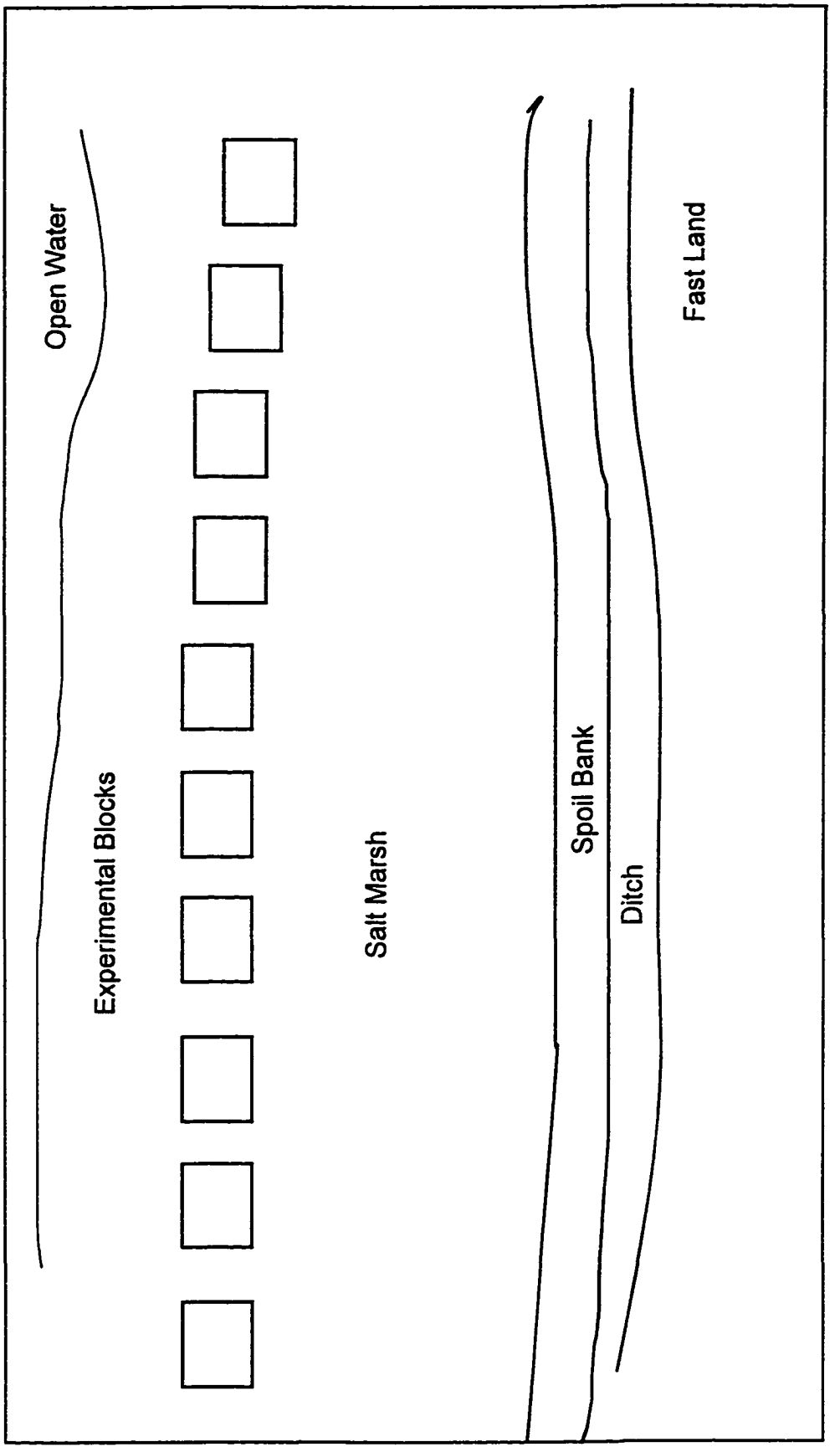

Figure 3.4 Block Layout

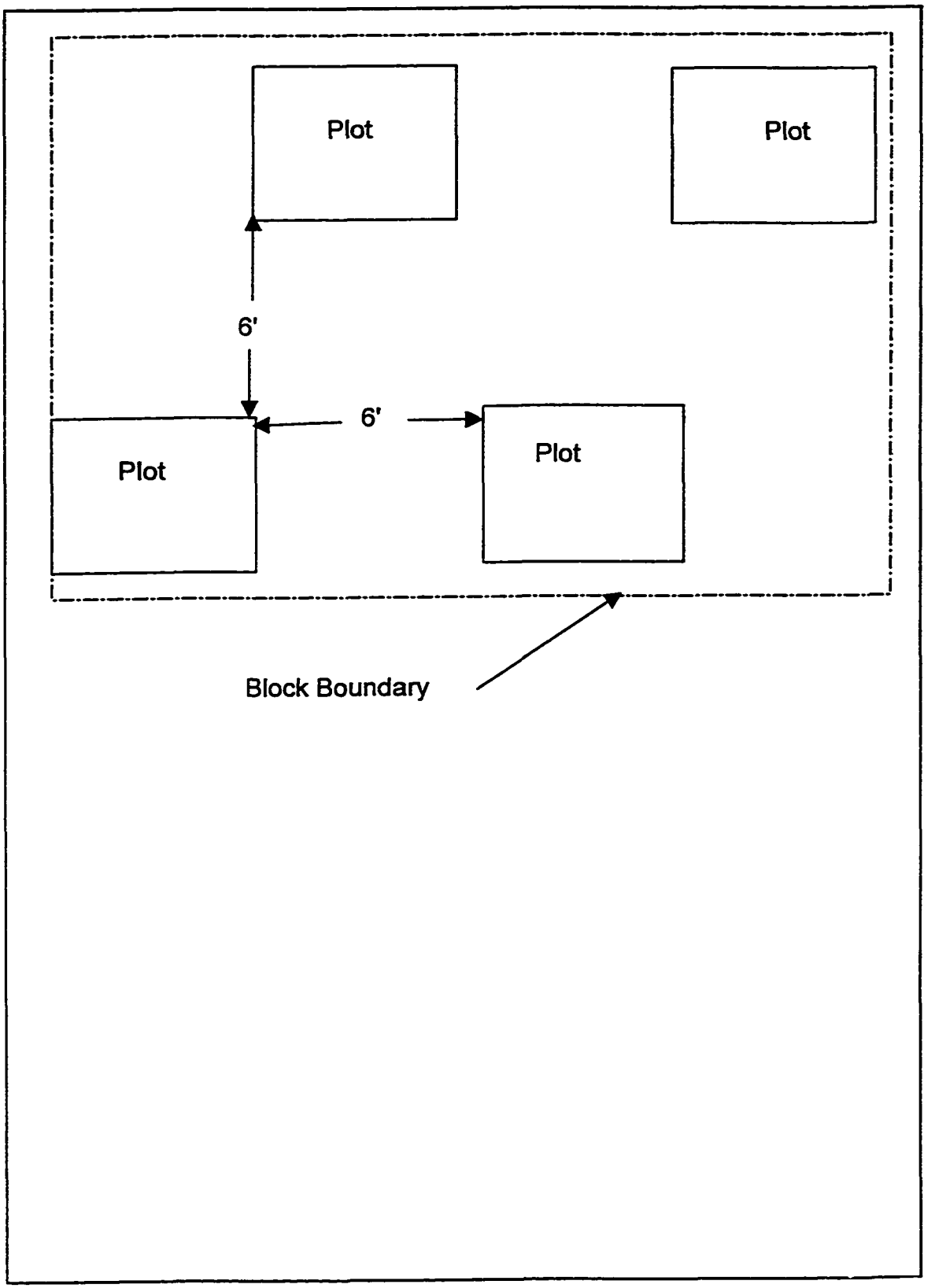

Figure 3.5 Plot Layout within a Block

Table 3.1 Time Line of Activities Field Plot Phase

Date	Day	Activity
1-Sep-97	-3	Set up plots
2-Sep-97	-2	Apply oil and fertilizer
4-Sep-97	0	Baseline sampling "Event A"
25-Sep-97	21	Event B Sampling
16-Oct-97	42	Event C Sampling
18-Nov-97	75	Event D Sampling
10-Dec-97	97	Event E Sampling
19-Jan-98	137	Event F Sampling, Refertilize after Sampling
9-Feb-98	158	Event G Sampling
4-Mar-98	181	Event H Sampling

event. The soil was removed using a bulb coring tool to a depth of 5 cm. An equal amount was removed from each of the four random locations to result in about one-half to one liter volume of soil. The composited sample from oiled plots was placed in a one liter glass jar.

The oil was extracted from the soil and the extract analyzed by GC/MS. The concentration of each of 18 indicator compounds was compared to the concentration of hopane which was used as a stable marker (Prince et al, 1994). Comparison of the oil was done using only the n-alkanes plus pristane and phytane since none of the PAHs had concentrations in the extracted oil of over a few nanograms. Details of the extraction procedure are in Appendix A. A list of the indicator components monitored and details concerning the operation of the GC/MS are in Appendix D.

3.2.4.2 Porewater and Soil Nutrients

As with the mesocosms, pH, and dissolved oxygen (DO) were initially monitored in the field plots porewater to determine if differences exist between treatments. The first several sampling events revealed that pH was consistently within a few tenths of 7 in all plots and DO was consistently a few tenths of a mg/l in all plots. Since field conditions were damaging the instruments, and the variation in the measurements taken were not judged significant, taking of pH and DO measurements was terminated.

Porewater was collected every 3 to 6 weeks and analyzed for nitrate and ammonia to document the retention, or lack thereof, of N in the salt marsh and to determine if reapplication of a nutrient was needed. Bragg (1993) had recommended that nitrogen in the porewater itself should be the primary field monitoring parameter.

The porewater was collected with a rigid piece of perforated plastic tubing connected by a piece of flexible tubing to a 3-way valve and a 60 ml syringe. Approximately 60 ml of porewater was collected from just below the marsh surface from each plot, placed in labeled plastic bottles, and placed on ice. The water was collected by inserting the tip of a plastic tube connected to the syringe several inches below the marsh surface.

Nitrate was analyzed using a Hach model DR/2000 spectrophotometer using NitroVer 5 chemical pillows. A direct reading of nitrate as N in mg/l was obtained. Depending on the clarity of the sample, analysis was either made of clear liquid poured from the sample container, or of filtered liquid.

Ammonia was analyzed using an ammonia specific electrode (Hach catalog number 50250-00), connected to a combination pH/millivolt meter. Known ammonia concentrations were used to prepare a calibration curve of concentration versus millivolt response. The ammonia concentration in an individual sample was determined from its millivolt reading and reference to the calibration curve.

Soil samples were also extracted to determine the mass of ammonia either bound to the soil or within the pore space. The procedure used was a modification of that of Keeney and Nelson (1982) for equilibrium extraction of ammonium from soil samples. For the ammonia extraction, approximately 10 grams of wet soil (about 1 gram dry soil) was placed in a 50 ml plastic centrifuge tube. 10 ml of 1 M NaCl solution was added. The centrifuge tubes were then shaken for at least 3 hours and centrifuged. The liquid portion was analyzed for ammonia using the ammonia ion specific electrode, in the same manner as was done for ammonia analyses in the porewater. Approximately 30 to 50 grams of wet soil was also oven dried to determine moisture content and calculation of the relationship

between wet and dry soil weight. The ammonia concentrations were expressed as mg ammonia-N per gram dry soil weight.

3.2.4.3 Microbe Counts

Counts of the number of microbes were made at three points in time in the field plots. The counts for total microbes were made by direct counts on pour plates. The most probable number (MPN) of oil degrading microbes was made by scoring replicates samples diluted to extinction using the sheen screen test (Brown and Braddock, 1990).

At the time oil extracts and ammonia extracts were being prepared, serial dilutions were made with marsh sediment. Details of the application of the serial dilutions to the pour plates are in Appendix B. Details of the methods of preparing the segmented trays for MPN counts is in Appendix C.

Determinations were expressed in terms of number of colony forming units (CFUs) per gram of dry soil for the pour plates or most probable number of oil degraders per gram of dry soil for the samples scored using sheen screen.

3.3 Results and Discussion

3.3.1 Visual Observations

No stress was observed to the *S. alterniflora* from the oiling of the field plots at an application rate of 1.41 liters per square meter, possibly since care was taken to direct the oil to the marsh surface and not to upper portions of the plants. The minimal tidal fluctuation (see Figures 3.2 and 3.3) may also have contributed to the minimal damage as documented by Mendelssohn et al (1990) and Smith et al (1984). Walking in the marsh, however, caused trampling of plants in the most widely used pathways, sometimes with the result of mud holes. Two foot by eight foot plywood sheets were laid on the marsh in the most heavily traveled areas to minimize the magnitude of the mud holes created. The field plots themselves

were not stepped into, and as a result they remained patches of healthy marsh with, in some cases, mud or open water adjacent to their boundaries.

Placement of the plywood on the marsh surface either encouraged visits from marsh mammals or else simply defined a common pathway for the human and animal visitors. Droppings were observed along this pathway from rabbits, a carnivorous animal believed to be a coyote, and a herbivorous animal believed to be a nutria. Rabbit droppings were occasionally observed within the plots. While there were no cattle such as plagued Mearns et al (1993) in the Marrow Marsh study by supplying "a significant chronic source of microorganisms, nutrients, and organically rich material to the marsh", the resident animals undoubtedly contributed to nutrient levels. Plot treatments had been assigned on a random basis so presumably all plot types received equal contributions.

3.3.2 Fraction of Oil Remaining

As in the mesocosm studies, the item of interest is that portion of the oil which is biodegraded. Accordingly, rather than expressing the decline of oil content on an absolute basis, which would include not only losses due to biodegradation, but also due to dispersion in the marsh, the amount of oil component remaining is expressed as the ratio of its mass to the mass of a stable marker, hopane. The assumption is that dispersion of the hopane will be approximately the same as for the other oil components, and that the change in compound to hopane ratio over time will represent that portion of the decline of the compound mass due to biodegradation.

The oil, as initially extracted at the baseline sampling, had a unique fingerprint, or relationship between its components. This fingerprint is expressed in terms of the ratio of the mass of each compound to the stable marker, hopane. Each plot had its fingerprint which determined the initial conditions against which

biodegradation of the oil in that plot would be measured, however, at the initial sampling, the fingerprints for all plots were quite similar, since minimal change had taken place since the oil was applied. Figure 3.6 shows the average fingerprint of the oil at the baseline sampling event.

It will be noted that the fingerprint for the oil shows only alkanes. PAHs were analyzed for but never found in the oil used in significant enough quantities to merit evaluation. Seldom was any PAH component found at over a few nanograms, while the alkanes used typically were on the order of tens to hundreds of nanograms.

During the progress of the study the average compound to hopane ratios of a given treatment were monitored to determine whether the oil was degrading faster in one treatment than another. This comparison was done by summing the mass of each compound from dodecane to hexatriacontane in a plot and dividing by the mass of hopane. The sum of compounds to hopane ratio for each plot divided by the same ratio from the baseline sampling event resulted in a fraction of oil (as based on the monitored compounds) remaining. The average fraction of oil remaining across the ten replicates of a treatment was determined. The result is a fraction for each treatment, determined at each sampling event, which, if biodegradation were the only loss process, would represent the fraction of initial oil remaining.

At each sampling event a graphical comparison was made of the performance of the treatments as described above. Figures 3.7 through 3.13 depict the fraction of oil remaining at each sampling event as measured by the total of the compounds from dodecane through hexatriacontane. These graphs show the average fraction remaining over all the plots of a treatment and the

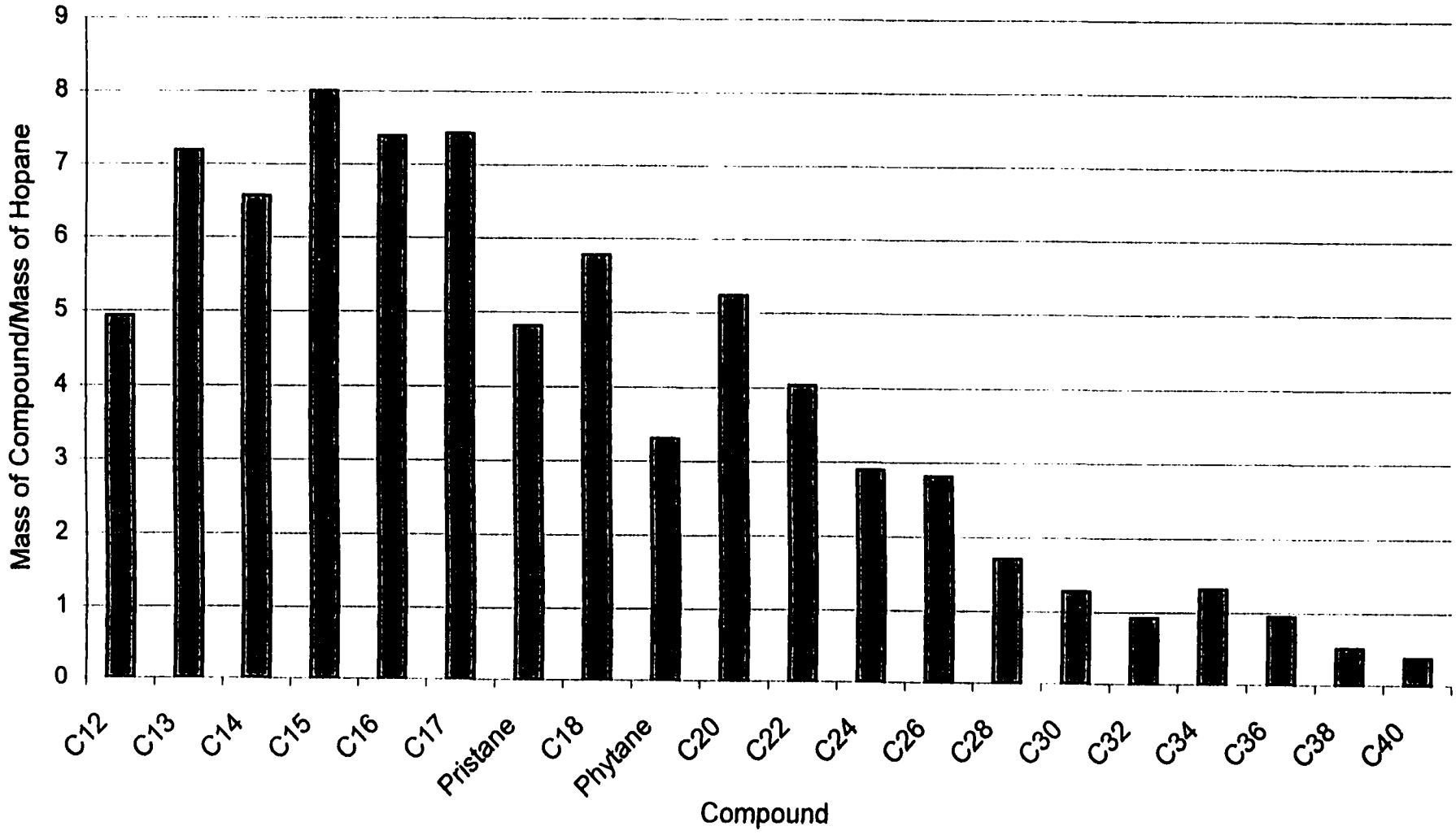

Figure 3.6 Initial Fingerprint of Oil Applied to Field Plots

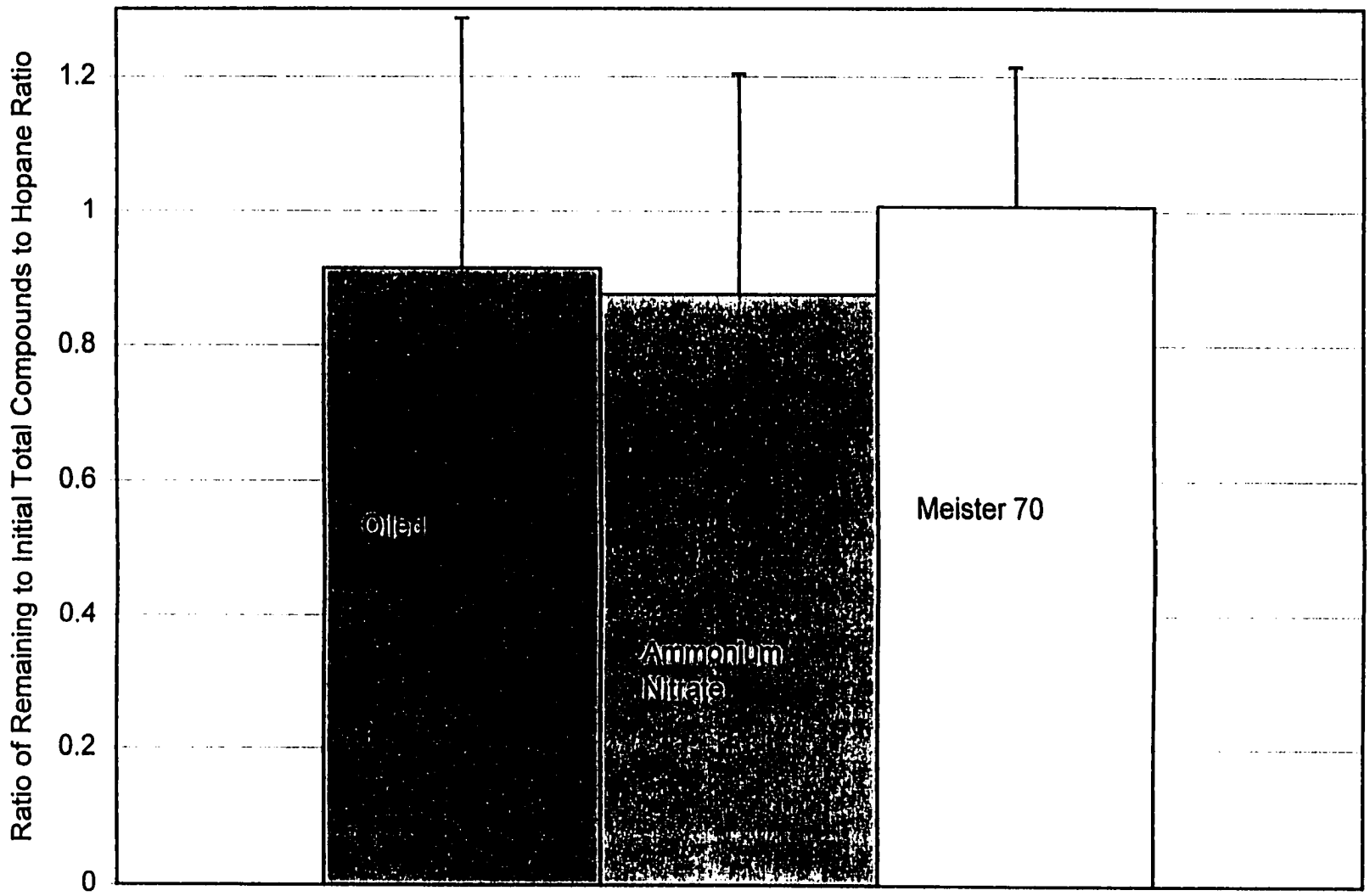

Figure 3.7 Fraction of Total Compounds to Hopane Ratio Remaining at 21 Days

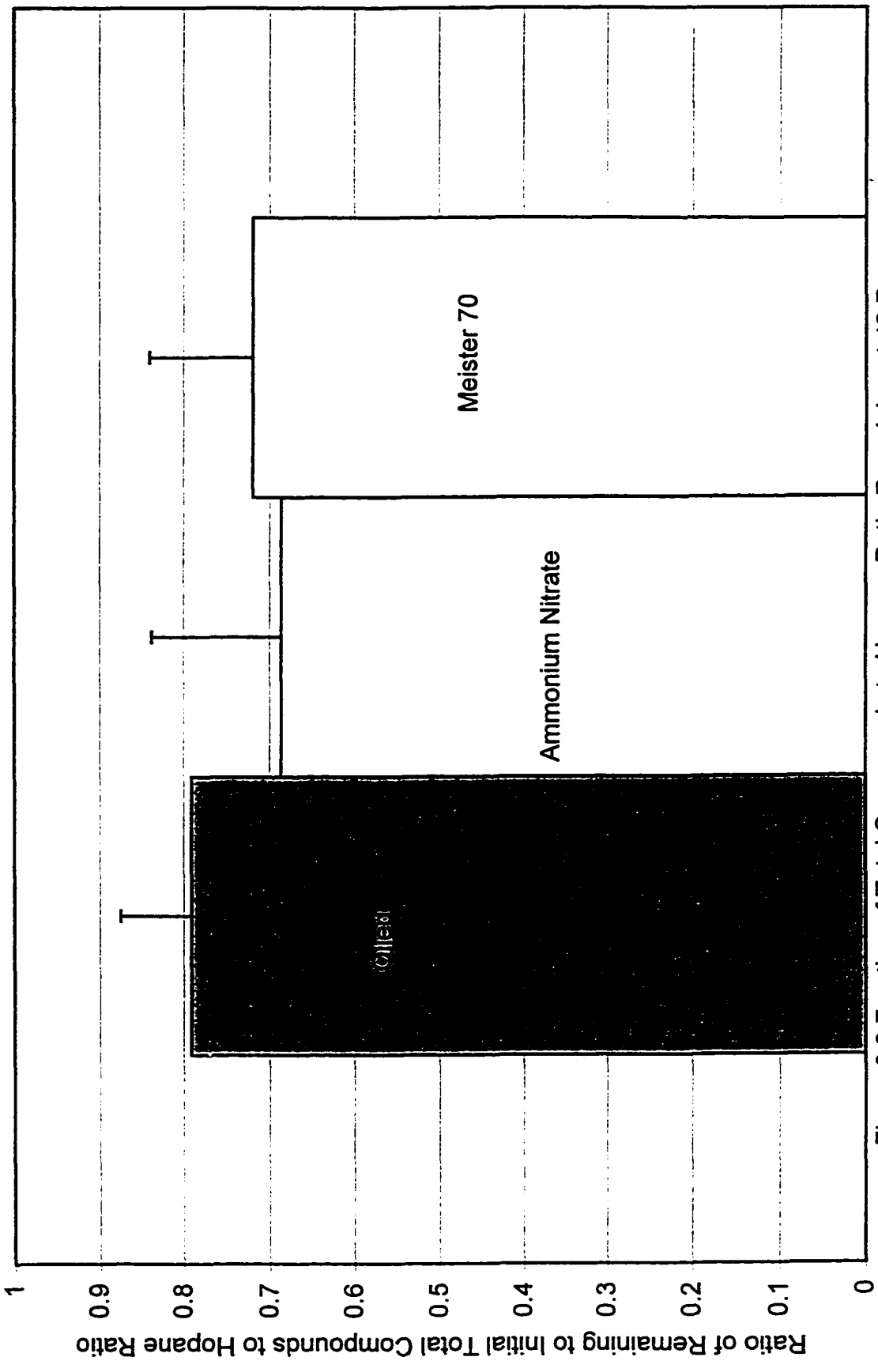

Figure 3.8 Fraction of Total Compounds to Hopane Ratio Remaining at 42 Days

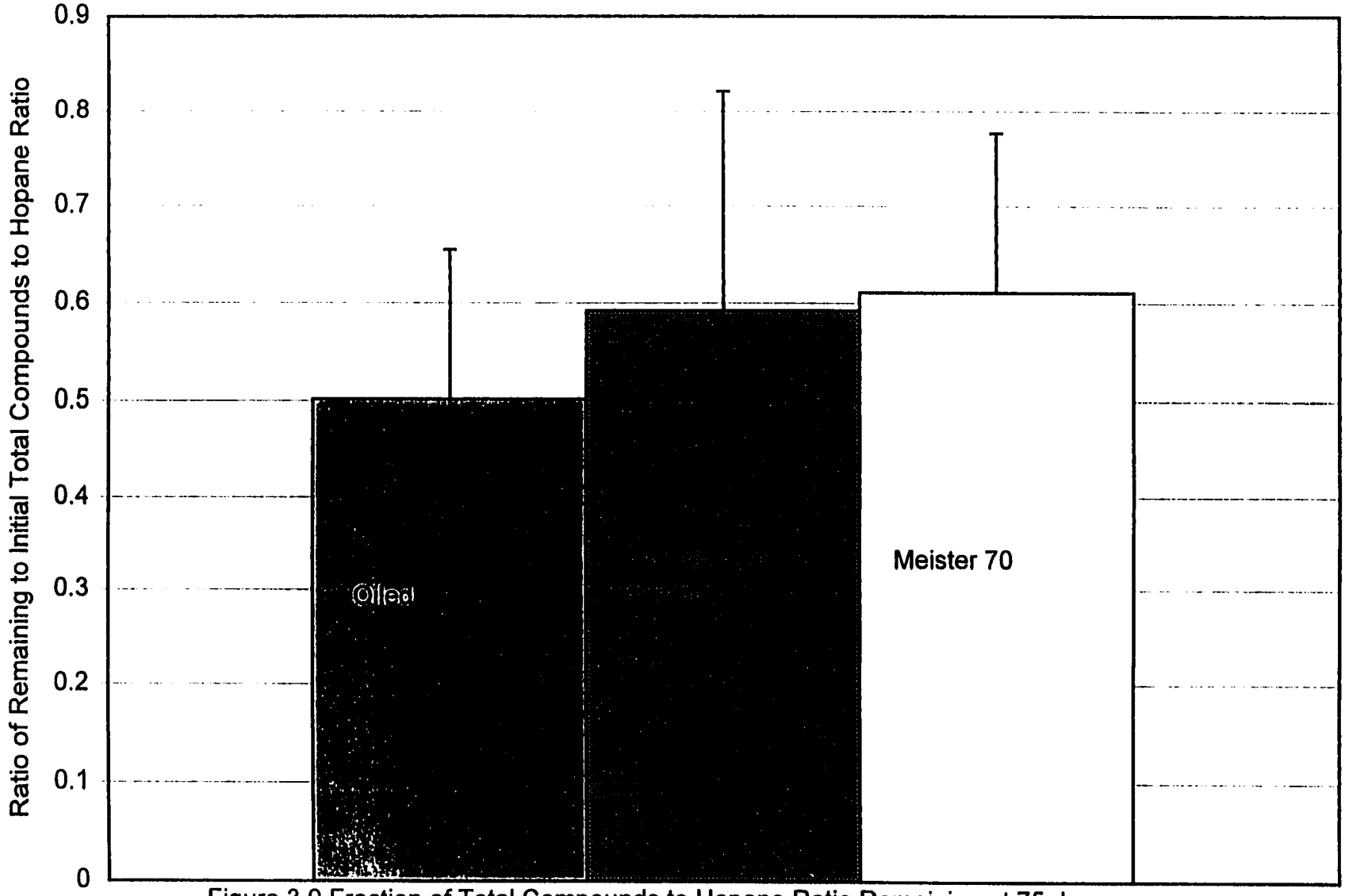

Figure 3.9 Fraction of Total Compounds to Hopane Ratio Remaining at 75 days

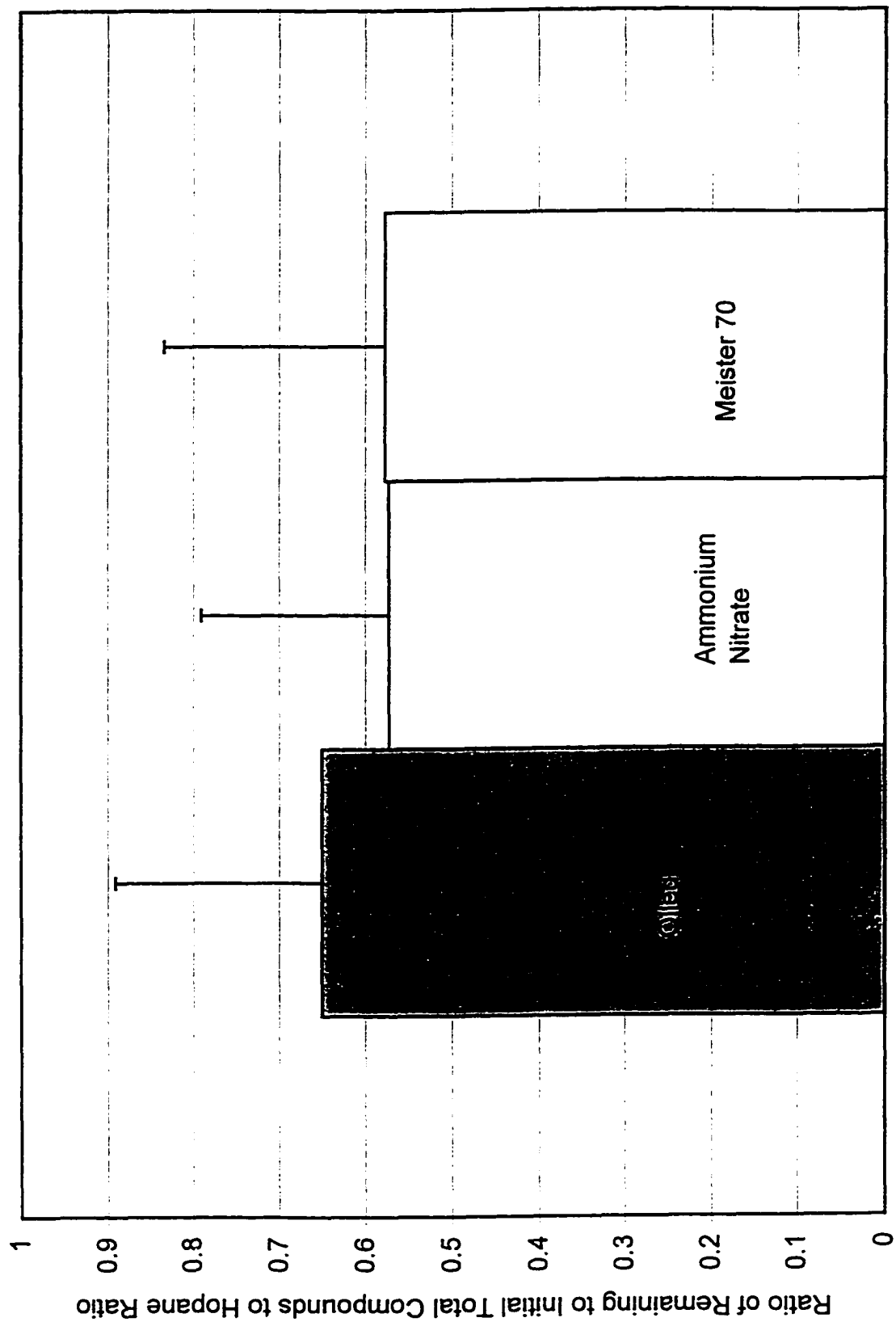

Figure 3.10 Fraction of Total Compounds to Hopane Ratio Remaining at 97 Days

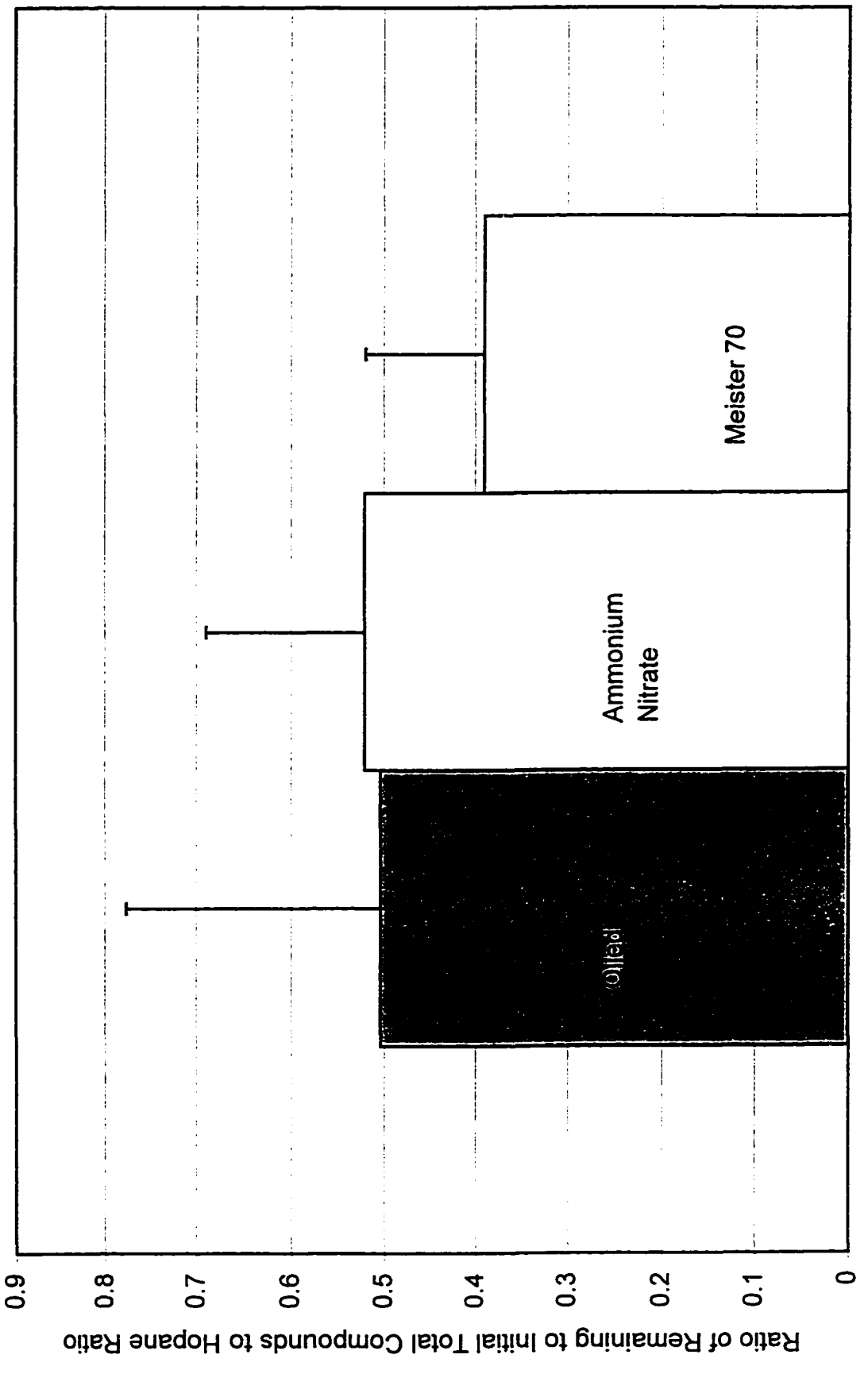

Figure 3.11 Fraction of Total Compounds to Hopane Ratio Remaining at 137 Days

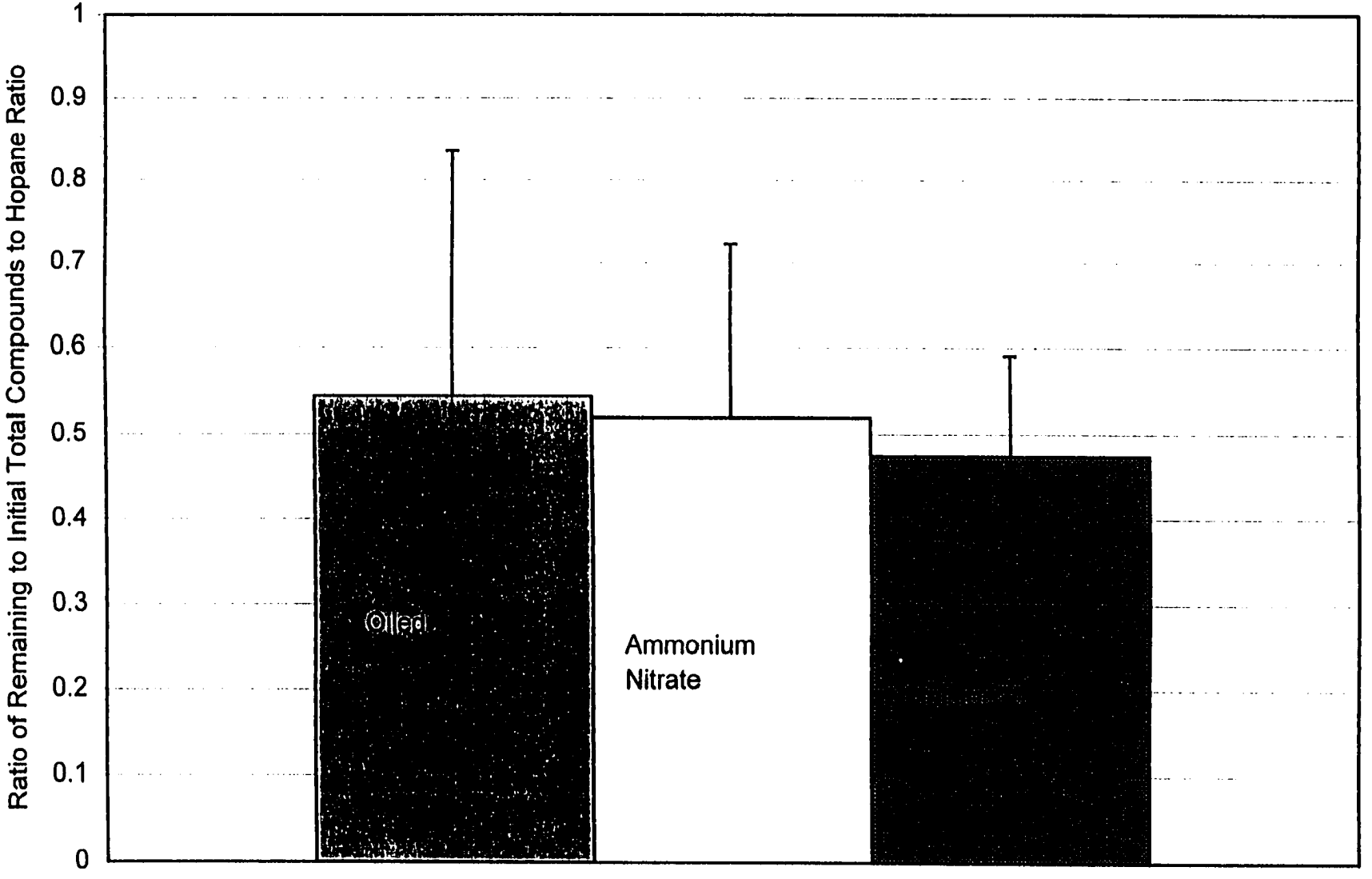

Figure 3.12 Fraction of Total Compounds to Hopane Ratio Remaining at 158 Days

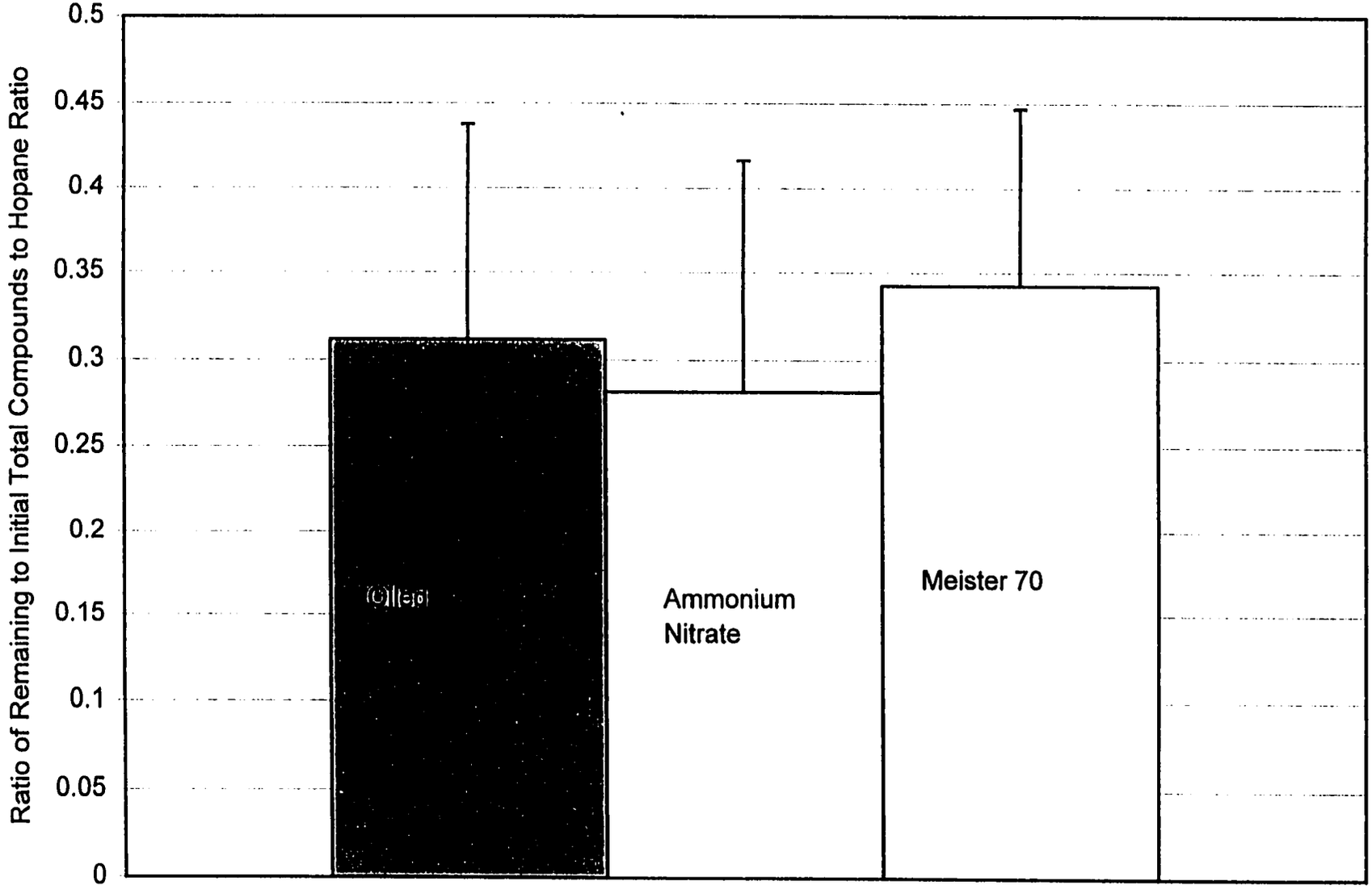

Figure 3.13 Fraction of Total Compounds to Hopane Ratio Remaining at 181 Days

standard deviation over all the plots of the treatment. Typically the average and standard deviation were based on all ten plots, however, at some sampling events insufficient oil was extracted to obtain a quantifiable amount of hopane. In this case the plot with insufficient oil was omitted from the statistical analyses for the event. It may be seen that throughout the study, the fraction of oil remaining was approximately the same for all treatments. The standard deviations for a given treatment were always large compared to the difference in the average values between treatments.

This similarity of performance of the different treatments is further depicted in Figure 3.14 which shows the average fraction remaining over time for all treatments. For clarity, no error bars are shown on this figure.

Of primary interest, however, is what quantitation can be made of the rate of degradation of the oil. Plotting the amount of oil remaining versus the amount initially present allowed for curve fitting the decline in oil content and determining decay parameters according to various conceptual models of the decay mechanisms.

Substrate limited decay usually may be approximated by first order biodegradation. The shape of the curves in Figure 3.14 also suggest that first order decay is appropriate, but that the curves may not approach zero as time progresses. Figure 3.14 also allows the interpretation that there may be a lag time before decay begins.

Non-linear curve fitting was done using first order degradation with the possibility of a lag time prior to the onset of degradation, and the possibility of some recalcitrance to biodegradation as represented by a non-zero asymptote as time approaches infinity. The program Table Curve 2D was used to conduct the

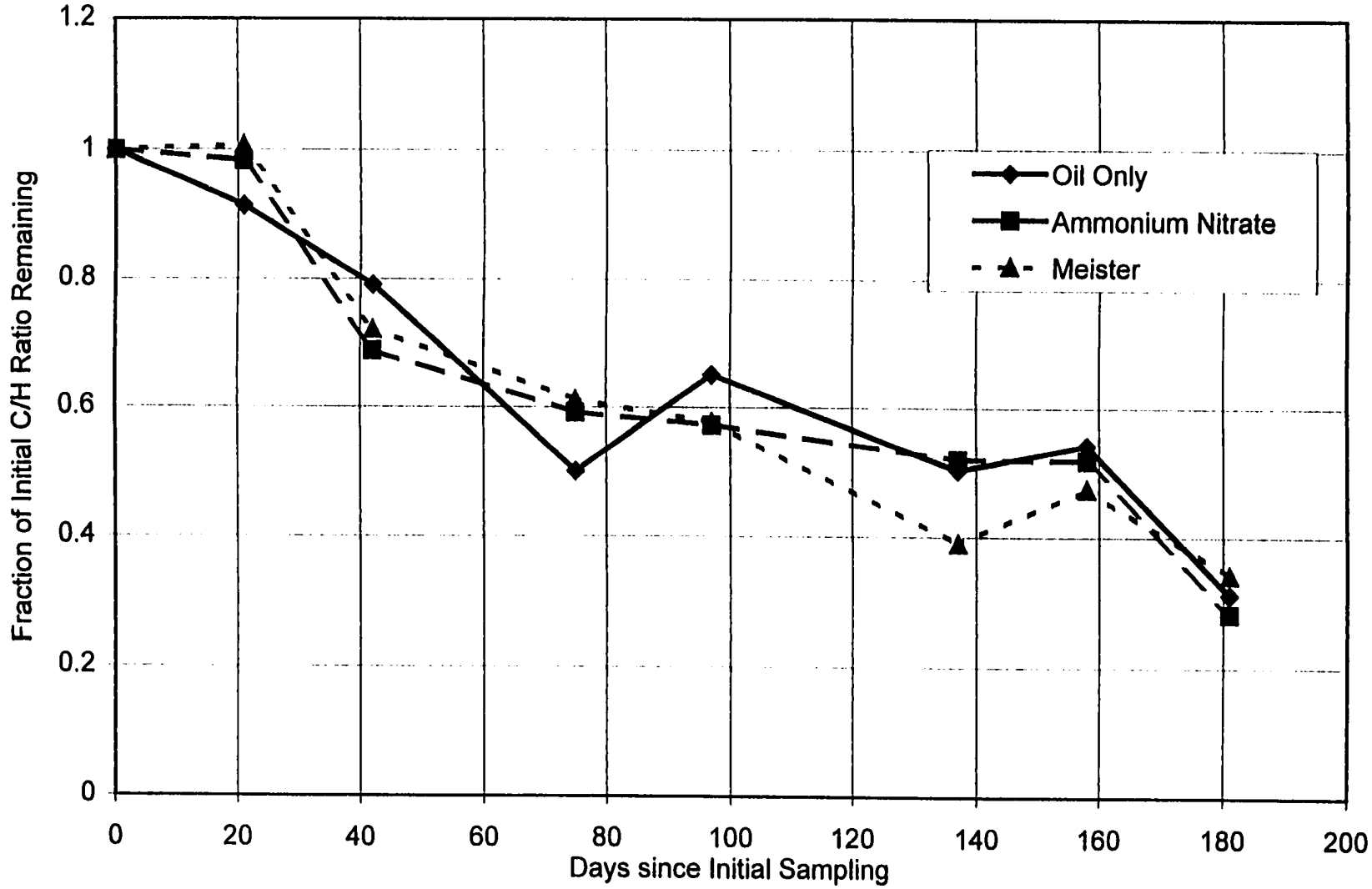

Figure 3.14 Average Fraction of Initial C/H Remaining vs Time

fits. Curve fitting of fraction of compound remaining was done for each of the 30 oiled plots, for each of the monitored oil components (dodecane through hexatriacontane) using four possible curve types to include possible lag time and recalcitrance. Incorporation of lag times into the first order decay expression was not found to add to the representation of the decay, however, for some compounds consideration of a non-zero asymptote was found to better represent the decay. The kinetics were found to be well represented by two of the four possible fitting curves, one with and one without a recalcitrance factor.

The first order expression of biodegradation is $y=\exp(-kt)$; where y is ratio of oil component to the amount initially present, k is the first order kinetic parameter expressed as 1/day, and t is the time in days since baseline sampling. The recalcitrance form of the biodegradation expression is $y=(1-b)+b\ \exp(-k't)$; where y is the ratio of oil component to the amount initially present, b is the fraction of oil component ultimately degradable as determined by the asymptote, k' is the first order kinetic parameter expressed as 1/day, and t is the time in days since baseline sampling. Obviously k and k' are not interchangeable.

The parameters k, k', and b were determined for 18 individual components of the crude oil and for the sum of the components. Table 3.2 contains the average values and standard deviations of k, k', and b by treatment type. For representation using first order kinetics, in six cases the Student's t-test at the 0.05 level of significance found the use of nitrogen amendment to result in a greater k than for the control. These six cases are in bold in Table 3.2. It is also recognized that if a large number of t-tests are conducted, that some of them will indicate significance even if the process as a whole is not significant. To check for overall significance, Boneferroni's method was used to calculate an overall t-test statistic based on a level of significance of 0.05 divided by the number of t-tests, in

Table 3.2 Rate Parameters for Degradation of Various Oil Components by Treatment - Field Plots

Compound	Treatment	1st Order K 1/day	RECAL K' 1/day	RECAL Fraction Degradable
Dodecane	Oiled	0.00443	0.00839	0.73912
Dodecane	Ammonium Nitrate	0.00594	0.01093	0.76145
Dodecane	Meister 70	**0.00772**	0.01252	0.77768
Tridecane	Oiled	0.00529	0.00924	0.81885
Tridecane	Ammonium Nitrate	0.00648	0.01272	0.75976
Tridecane	Meister 70	**0.00708**	0.01017	0.71395
Tetradecane	Oiled	0.00527	0.00959	0.60916
Tetradecane	Ammonium Nitrate	0.00676	0.01448	0.63961
Tetradecane	Meister 70	**0.00721**	0.01239	0.73665
Pentadecane	Oiled	0.00593	0.00926	0.73792
Pentadecane	Ammonium Nitrate	0.00613	0.01429	0.76528
Pentadecane	Meister 70	0.00660	0.00951	0.77018
Hexadecane	Oiled	0.00597	0.00971	0.73708
Hexadecane	Ammonium Nitrate	0.00656	0.01380	0.79006
Hexadecane	Meister 70	0.00654	0.00922	0.76491
Heptadecane	Oiled	0.00683	0.01029	0.77323
Heptadecane	Ammonium Nitrate	0.00764	0.01146	0.86870
Heptadecane	Meister 70	0.00655	0.00823	0.84067
Pristane	Oiled	0.00078	0.00127	0.98365
Pristane	Ammonium Nitrate	**0.00191**	0.00669	0.25936
Pristane	Meister 70	**0.00196**	0.00516	0.36900
Octadecane	Oiled	0.00559	0.00864	0.73350
Octadecane	Ammonium Nitrate	0.00598	0.00973	0.76254
Octadecane	Meister 70	0.00637	0.00891	0.78314
Phytane	Oiled	0.00120	0.00134	0.99871
Phytane	Ammonium Nitrate	0.00186	0.00332	0.32216
Phytane	Meister 70	**0.00209**	0.00514	0.32395
Eicosane	Oiled	0.00537	0.00786	0.70595
Eicosane	Ammonium Nitrate	0.00636	0.01053	0.79076
Eicosane	Meister 70	0.00599	0.00880	0.74811

Table 3.2
Continued

		1st Order	RECAL	
				Fraction
Compound	Treatment	K 1/day	K' 1/day	Degradable
Docosane	Oiled	0.00661	0.01016	0.79348
Docosane	Ammonium Nitrate	0.00804	0.01380	0.86167
Docosane	Meister 70	0.00709	0.00991	0.79463
Tetracosane	Oiled	0.00707	0.01094	0.80628
Tetracosane	Ammonium Nitrate	0.00748	0.01984	0.80260
Tetracosane	Meister 70	0.00712	0.01041	0.81558
Hexacosane	Oiled	0.00680	0.01106	0.80600
Hexacosane	Ammonium Nitrate	0.00832	0.01448	0.86786
Hexacosane	Meister 70	0.00753	0.00949	0.80260
Octacosane	Oiled	0.00763	0.01131	0.92823
Octacosane	Ammonium Nitrate	0.00711	0.01539	0.82061
Octacosane	Meister 70	0.00720	0.01043	0.82180
Triacontane	Oiled	0.00785	0.01184	0.83409
Triacontane	Ammonium Nitrate	0.00663	**0.01834**	0.77096
Triacontane	Meister 70	0.00707	0.01288	0.70563
Dotriacontane	Oiled	0.00703	0.01294	0.84326
Dotriacontane	Ammonium Nitrate	0.00541	0.01552	0.70872
Dotriacontane	Meister 70	0.00573	0.01189	0.67564
Tetratriacontane	Oiled	0.00342	0.03332	0.55145
Tetratriacontane	Ammonium Nitrate	0.00305	0.01838	0.37544
Tetratriacontane	Meister 70	0.00250	0.01069	0.37415
Hexatriacontane	Oiled	0.00633	0.03363	0.61318
Hexatriacontane	Ammonium Nitrate	0.00374	0.02478	0.43390
Hexatriacontane	Meister 70	0.00256	0.01946	0.33720
Sum of Alkanes	Oiled	0.00544	0.00918	0.72332
Sum of Alkanes	Ammonium Nitrate	0.00590	0.01209	0.72081
Sum of Alkanes	Meister 70	0.00580	0.00882	0.71045

this case 36 (18 oil components with two treatments each). The overall effect is evaluated with a significance of 0.05/36=0.00139. None of the cases showed significance at this level, therefore, it is possible that no significance exists. From the engineering viewpoint, the small number of cases where the hypothesis was proven at the 0.05 significance has no practical application.

This ineffectiveness of fertilizer to increase the biodegradation rate is in contrast to Bragg et al's (1993) experience on an Alaskan beach after the Valdez spill. It is, however, in agreement with Jackson's (1996) field plot studies. The ineffectiveness of the fertilizer to speed biodegradation is also in contrast to Venosa et al's (1996) Delaware beach experience in which every straight chain alkane from C_{10} to C_{35} plus pristane and phytane experienced a significant increase of degradation rate in the presence of fertilizer. Venosa et al (1996) did not report dissolved oxygen concentrations, but it appears their plots were not severely oxygen limited since they were out of the water from 13 to 23.5 hours a day. The plots higher on the beach with shorter duration of submersion also had faster degradation rates.

Figure 3.15 is a bar graph of the first order kinetic rate parameter, k, for the various compounds for the control, for treatment with ammonium nitrate, and for treatment with Meister 70 time release urea. A complete table showing the kinetic parameters as determined in each plot is in Appendix G. The range of variability between plots is readily apparent. The actual data sets of fraction of compound remaining versus time that were used in the curve fitting are in Appendix E.

Despite the ineffectiveness of the nutrient addition, the research demonstrated the degradation of crude oil even in the control plots. While this data is strictly applicable only to the site conditions, it can offer guidance on the order of magnitude natural attenuation rates and especially of biodegradation

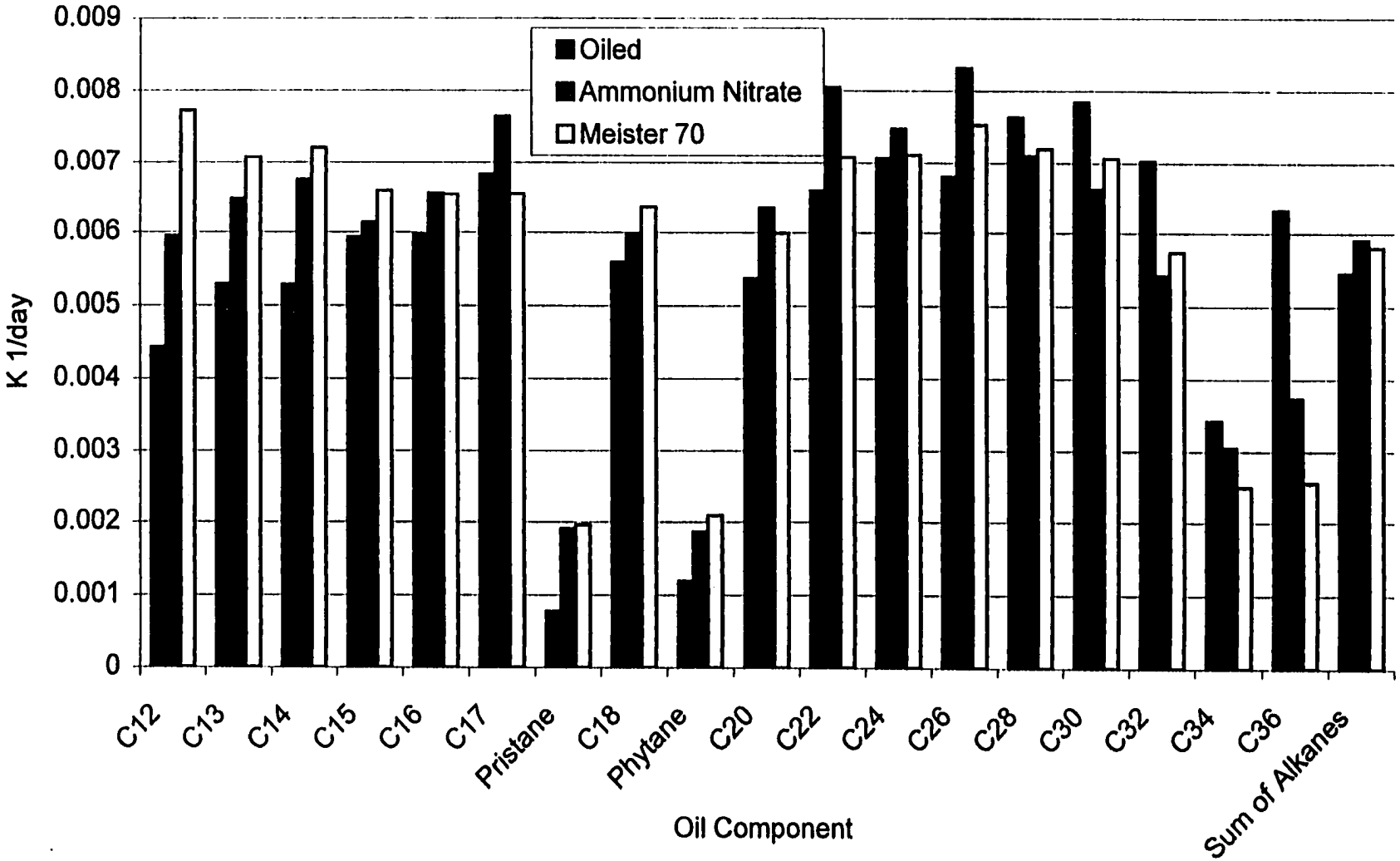

Figure 3.15 First Order Rate Parameter K by Treatment and Oil Component

rates of individual components. Such information is extremely useful in forecasting the fate of a spill if left to fend for itself. Use of these data in such forecasting will be demonstrated in the following chapter.

Of interest is the difference in the range of kinetic parameters as determined by the field plots versus those of the mesocosms. The first order decay rates k as determined in the mesocosms were several times those found in the field. An evaluation was made as to whether the difference in temperature between the lab where the mesocosms were kept and the average temperature over the life of the field plots could account for this difference. This evaluation is in Appendix J. The writer concluded that the difference in rate parameters cannot be attributed to a slowing of biological processes with cooler temperatures. The difference observed may be due to the effects of temperature on the solubility of oxygen in water, or on the tidal variations experienced in the field which were not mimicked in the lab. Whatever the cause of the difference between the field derived rate parameters and the mesocosm rate parameters, they do not invalidate the conclusions regarding the performance of the treatments versus the control since all plots experienced the same field conditions. The differences of lab to field should warn one to be wary of extrapolating mesocosms to field conditions. Despite common oil and fertilizer loading rates the climatologic conditions experienced in the field cannot be duplicated in the lab.

3.3.3 Porewater Nutrient Concentrations

At each sampling event porewater samples were taken and analyzed for nitrate and ammonia. Figure 3.16 depicts the range of nitrate values. Nitrate concentrations were found to be elevated after the initial fertilization in the ammonium nitrate treated plots but to drop rapidly. Nitrate also dissipated rapidly after the second fertilization on day 137.

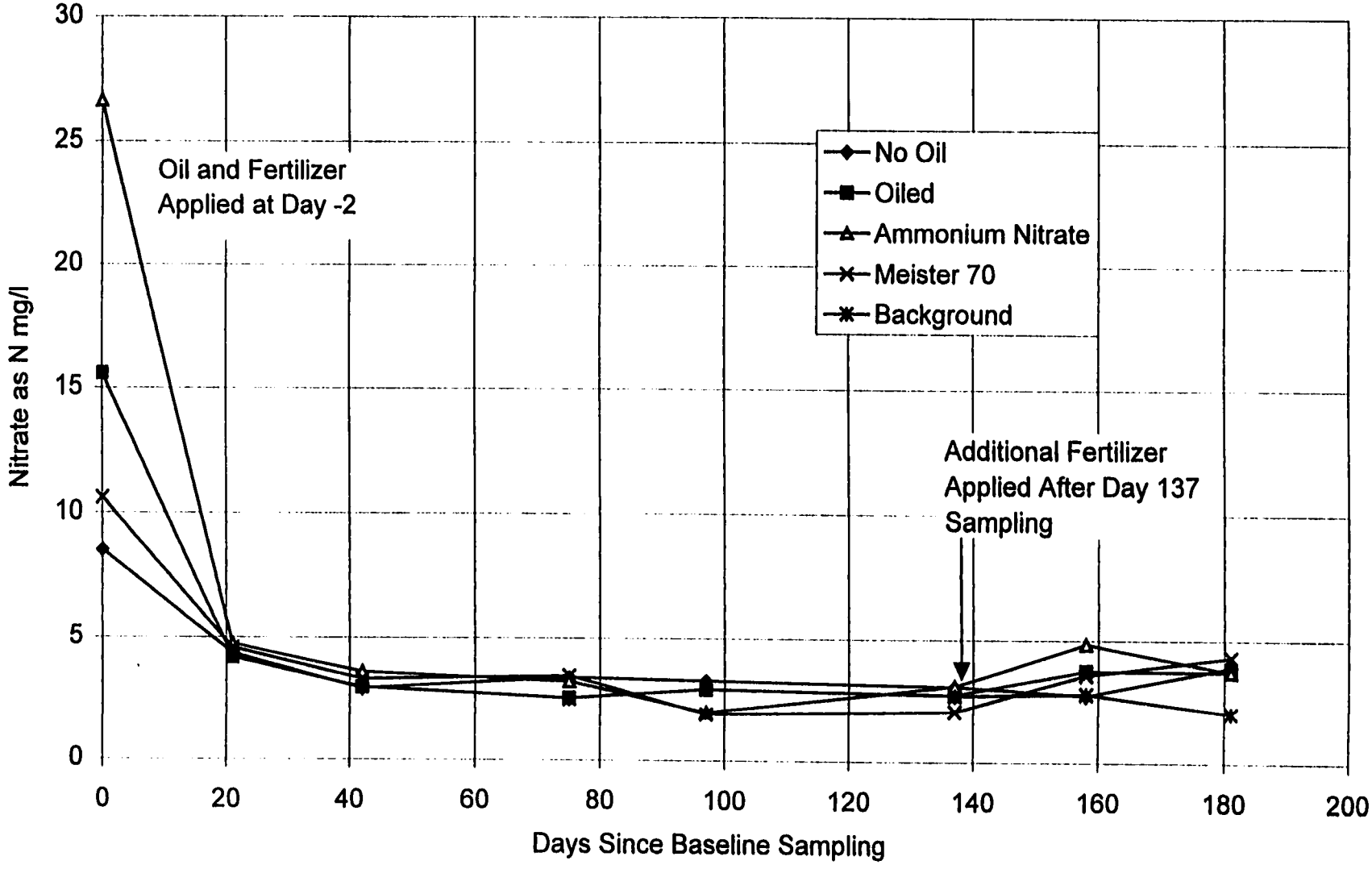

Figure 3.16 Average Porewater Nitrate vs Time by Treatment

Figure 3.17 depicts ammonia concentrations in the porewater. It also may be seen to be elevated after the initial fertilization on September 2, 1997 and to drop rapidly, although not as rapidly as the nitrate. Refertilization on day 137 (after the sampling on that date) resulted in a resurgence in concentrations, although it dissipated even faster after the second application than initially. It is unknown whether the even faster rate of dissipation of the ammonia at the second fertilization is due to the greater microbe counts, the season of the year, or some other factor.

3.3.4 Soil Extractable Ammonia

Figure 3.18 depicts the soil ammonia concentrations. Soil ammonia may be seen to not be as variable as porewater ammonia. The time release mechanism of the fertilizer appears to be working, however, based on the increased concentration of ammonia found at day 75 and day 181 which are 77 and 44 days after fertilizer application and reapplication respectively..

3.3.5 Microbe Counts

Counts of total microbes were made at the sampling events at day 75 and day 181. An attempt was made to count the microbes at the beginning of the project, however, none of the plates had growth, i.e. the counts were all lower than the dilutions prepared. At day 75 and day 181 less dilute plates were poured and valid counts were obtained. Table 3.3 tabulates the number of CFUs at 75 and 181 days. It may be seen that the number is highly variable as the standard deviation is large compared to the average. At 75 days, however, the ammonium nitrate plots had approximately ten times (log 9 versus log 8) as many microbes as the other plots. A similar increase had been observed by Prince (1992). At 181 days the difference between the plot types had decreased. The response in the total microbe counts appears to be an increase in numbers in the presence of the

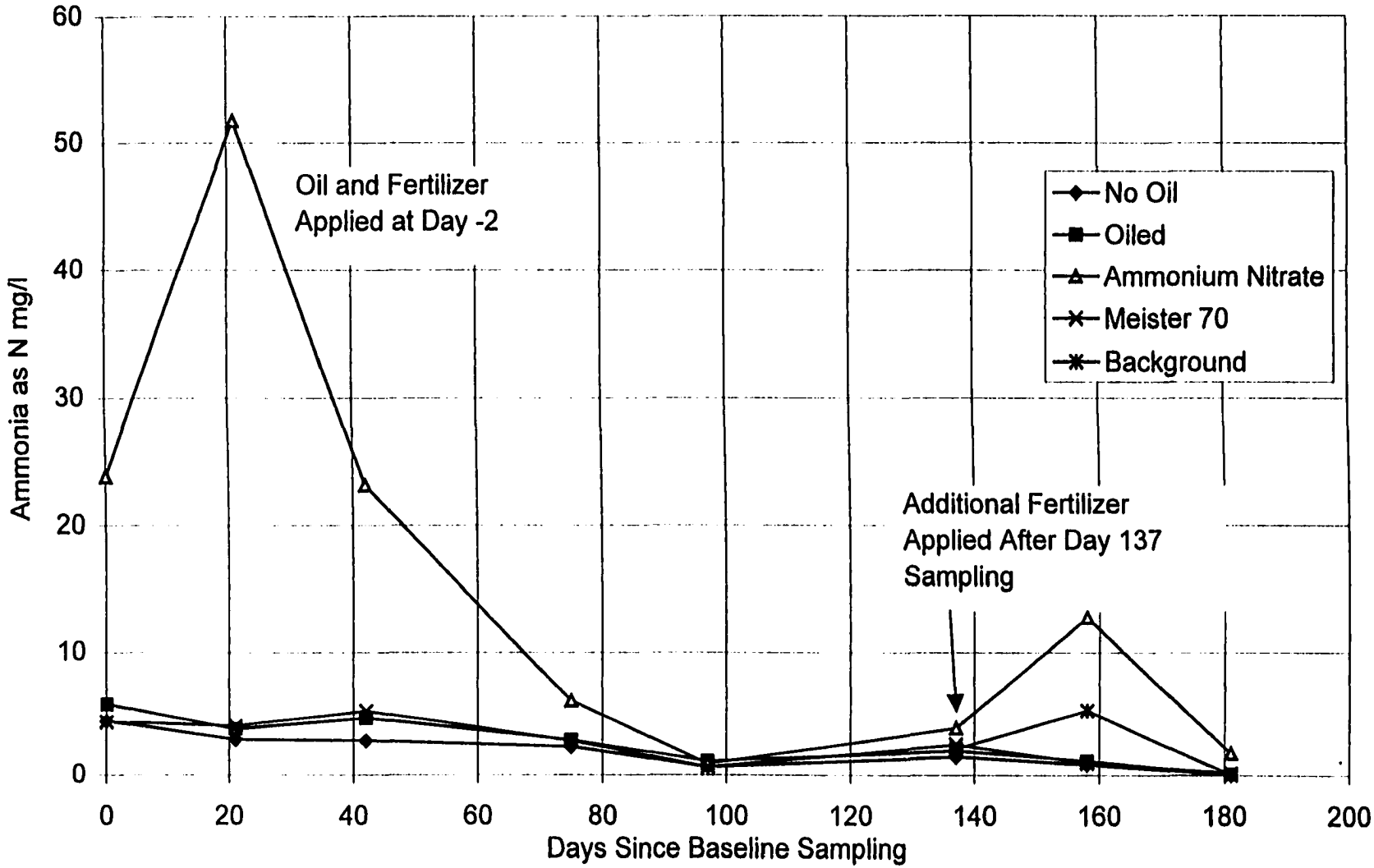

Figure 3.17 Average Porewater Ammonia vs Time by Treatment

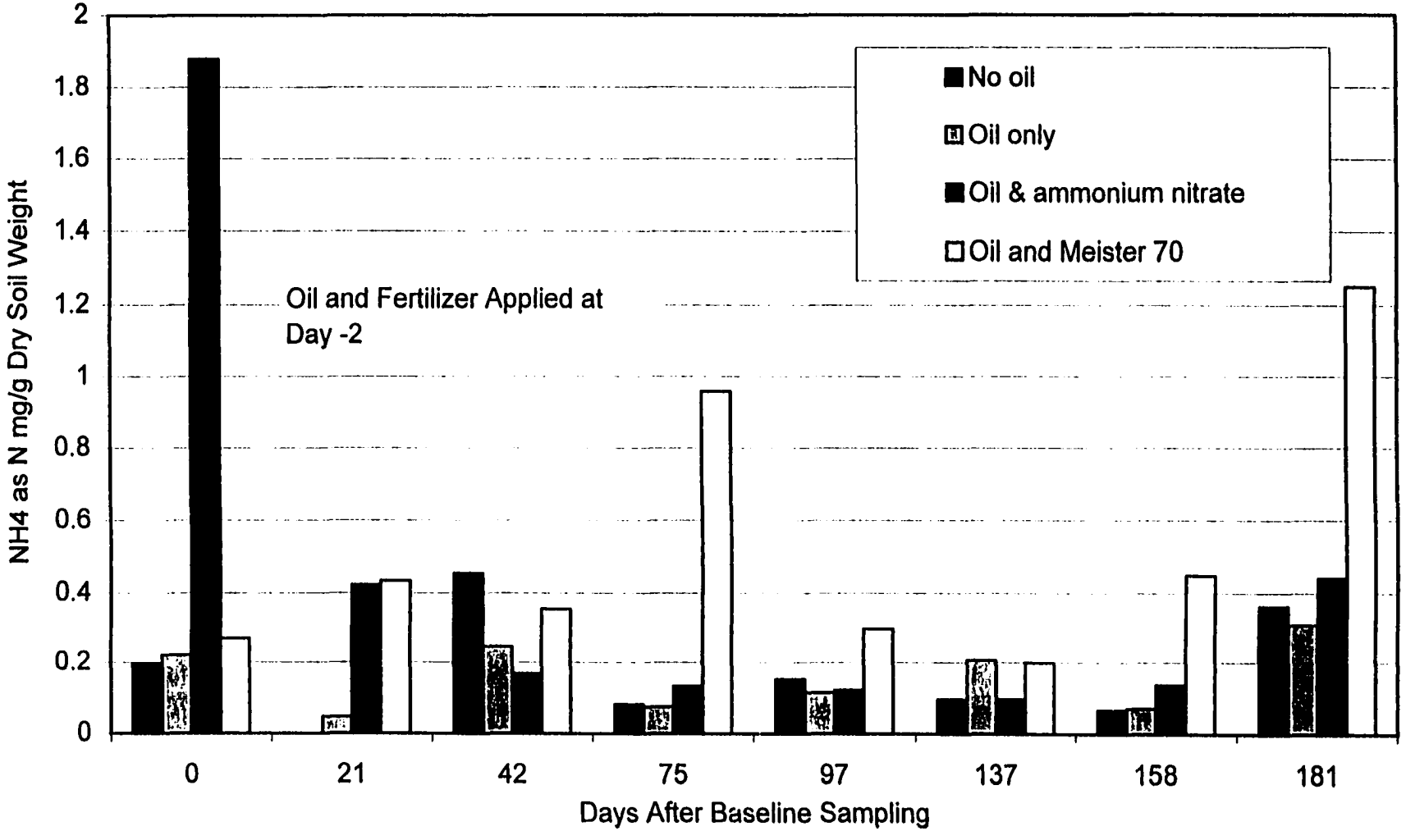

Figure 3.18 Average Ammonia Concentration in Soil vs Time by Treatment

ammonium nitrate rather than to the oil. The ammonium nitrate plots count of log 9.1 at day 75 is approximately an order of magnitude greater than the counts in the other plot types. The 75 day counts for total microbes are the only counts in which the averages were greater than the standard deviations.

Counts of oil degraders were made at the initial sampling event, and the sampling events at day 75 and day 181. Table 3.4 depicts the counts. It may be seen that the microbe counts at day 75 responded to a combination of oil and fertilizer, with a lesser response to oil without fertilizer. Both ammonium nitrate and Meister treatments results in increased MPNs by approximately one order of magnitude at day 75. Ammonium nitrate plots increase from log 4.8 at day 0 to log 5.7 on day 75. Meister plots increased from log 4.5 to log 5.8 over the same period. Control plots only increased from log 5.2 to log 5.5 and non-oiled plots declined in MPN. Past day 75, the Meister plots held steady in MPN while the control and ammonium nitrate plots declined in MPN.

Venosa et al (1996) had experienced similar numbers of alkane degraders (log 4.5 to log 6) in the oiled plots regardless of whether they were fertilized. Their unoiled plots had 1 to 2 orders of magnitude fewer alkane degraders. The number of alkane degraders declined throughout Venosa's study for both oiled and unoiled plots.

Variability between plots of a given treatment are large and the standard deviation for each plot type for MPN determination is as large or larger than the average count for the plot type.

3.4 Conclusions

3.4.1 Efficacy of Nitrogen Addition

In the *Spartina alterniflora* marsh studies, addition of neither ammonium nitrate nor time release urea significantly increased the rate of biodegradation of

Table 3.3 Total Microbe Counts in Field Plots

Log CFU/g Dry Weight Treatment	Day 75	Day 181
Non-oiled	7.99 ± 7.71	9.03 ± 9.10
Control	8.07 ± 7.48	8.72 ± 8.88
Ammonium Nitrate	9.12 ± 7.58	9.41 ± 9.76
Meister 70	8.18 ± 7.60	9.02 ± 9.30

Table 3.4 Oil Degrading Microbe Counts in Field Plots

Log MPN Oil Degraders/g Dry Weight Treatment	Day 0	Day 75	Day 181
Non-oiled	4.46 ± 4.74	3.78 ± 3.82	4.03 ± 4.28
Control	5.21 ± 5.59	5.51 ± 5.74	4.39 ± 4.63
Ammonium Nitrate	4.80 ± 4.97	5.73 ± 6.06	5.39 ± 5.63
Meister 70	4.50 ± 4.79	5.85 ± 5.95	5.86 ± 5.86

sweet Louisiana crude oil. The research is not without value, however. The foremost value is in the conclusion that adding nutrients in spills under similar conditions is likely not to be of benefit. Acknowledgment of the possibility of this conclusion will prevent wasting of time and resources attempting such an endeavor in a real situation, unless and until tests have shown nutrient addition to be useful in the situation at hand.

The conditions for this experiment should be remembered:

- Salt marsh
- Experimental period early September to early March
- Application of sweet Louisiana crude oil which was high in alkanes and low in polyaromatic hydrocarbons
- Application rate of 1.16 kg/square meter
- Normal tidal range a fraction of a foot, i.e. no significant coating of oil on plant parts
- Use of ammonium nitrate at 171g/square meter and Meister 70 time release urea at 75 g/square meter.

While the marsh conditions, oil type and application rate, and tidal range are expected to be representative of possible scenarios along the Louisiana coast, under different conditions the behavior would likely differ. Under some of these differing conditions the application of nutrients may prove beneficial.

Importantly, the results indicate a significant natural degradation rate of crude oil in salt marshes, even in the absence of nutrient addition.

3.4.2 Prediction of Oil Degradation Rates

Under the conditions studied it was demonstrated that the biodegradation of the sum of the n-alkane plus pristane and phytane fraction of a sweet Louisiana crude oil can be modeled as first order decay with a rate parameter of 0.0054/day.

This rate is in the same range noted by Lee et al (1993) on a low energy Nova Scotia beach, about an order of magnitude lower than Venosa et al (1996) found on a Delaware beach. See Table 1.1 for the comparison. The biodegradation of individual components can also be modeled as first order decay at the rates presented in Table 3.2. The determination of the rate parameters for crude oil degradation in the salt marsh will allow planning of monitoring of a spill in a cost effective manner and predicting its outcome and rate of reaching that outcome. The degradation rates also provide a baseline against which biodegradation in a salt marsh can be measured to determine if it is progressing unhampered by a shortage of nitrogen. Determination that decay rates are significantly less than those found here is cause to question whether some nutrient application would be of value. Determination that decay rates are not significantly different than those in this research are cause to accept conditions as unamenable to improvement by nitrogen addition.

3.4.3 Retention of Applied Nutrients

The tracking of the nutrient levels showed that nitrate and ammonia concentrations dropped within a matter of days from the concentrations applied. The Meister time release urea was shown to release its nitrogen approximately at its design release date (70 days). Ammonium nitrate will likely require reapplication every 20 to 40 days if elevated concentrations in the porewater are desired. This reapplication frequency is similar to the 40 day reapplication interval recommended by Bassere et al (1993).

3.4.4 Effect of Oil or Nutrients on Microbial Growth

Application of both the oil, and the combination of oil and nutrients resulted in increases in the number of microbes, however, the performance between plots of a given treatment was extremely variable with standard deviations exceeding

the mean. Despite the increase in average number of microbes with fertilizer application, the rate of oil degradation did not increase.

4. Engineered Bioremediation Management

The most important engineering application of this research is that nutrient addition should not be performed upon an oil spill in a salt marsh unless an engineering evaluation indicates that nutrient addition would be beneficial. To apply nutrients in the absence of indications of benefit would result in a waste of money, damage to the marsh by unnecessary entry, and risk of eutrophication due to application of excess nitrogen.

The above having been said, the writer, as a civil/environmental engineer recognizing that regulators will require documentation that a "no-action" alternative is best, is prompted to devise a program to identify those situations under which nutrient application might be of benefit and a plan to budget and execute such a nutrient application. The steps in such are program are

- Decide whether the severity of the spill requires cleanup in the marsh
- Decide on the degree of remediation required and whether it is likely to be attained under natural conditions including dispersion and biodegradation
- Monitor to confirm that the anticipated rate of natural attenuation is being achieved
- If necessary, conduct a pilot test of nutrient addition to speed the natural attenuation.
- Based upon the pilot test decide whether to implement full scale nutrient addition.

Figure 4.1 is a logic diagram which explains the relationships of these steps and the decisions made at each step.

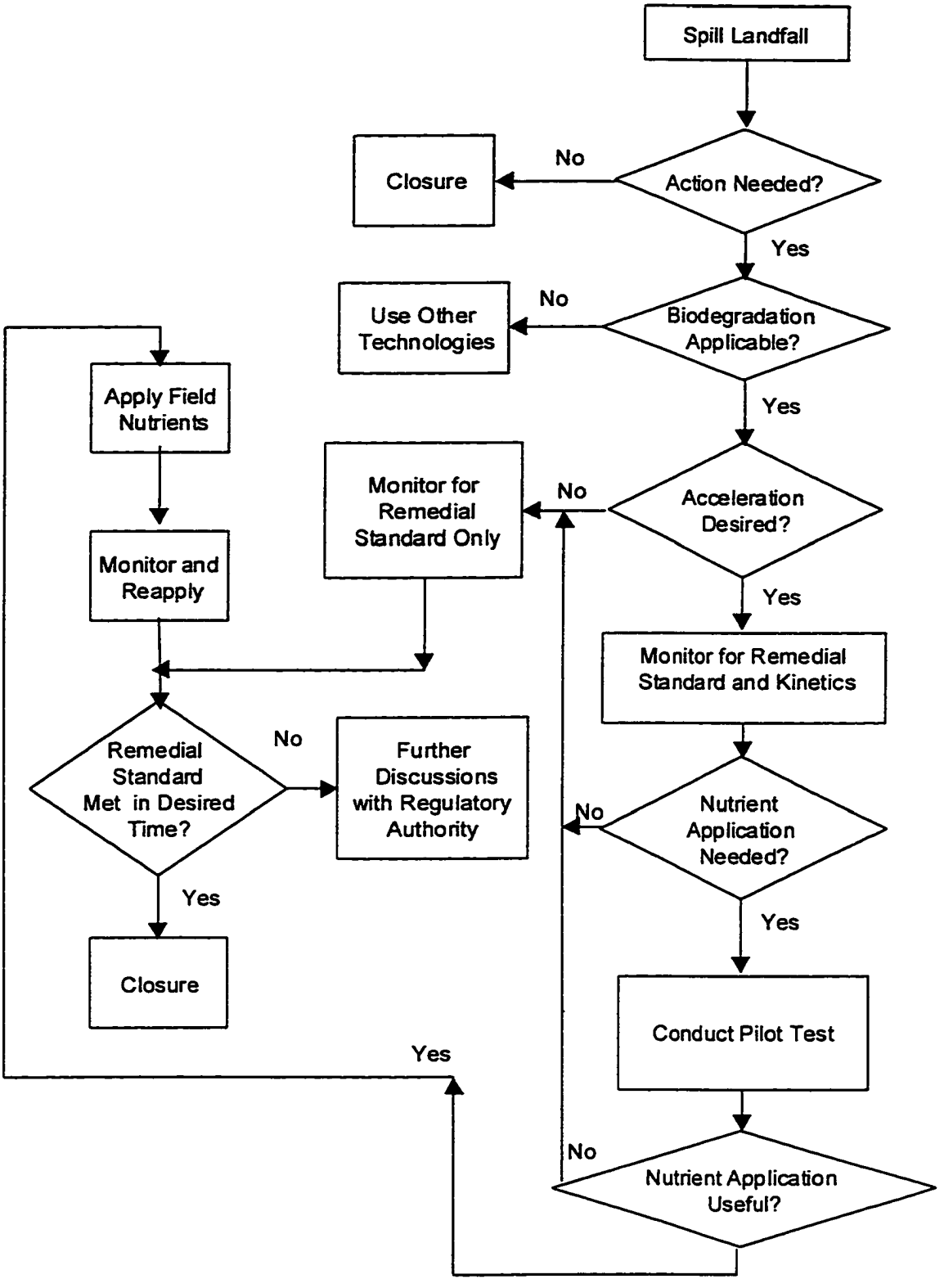

Figure 4.1 Logic Diagram for Engineering Oil Spill Bioremediation

4.1 Assessment of Severity of the Spill

This discussion considers only the disposition of the oil within the marsh. Traditional containment and removal technologies will presumably be used to remediate the portion of the oil spill which has not yet made landfall.

The first step is to decide whether any remediation of oil in the marsh is needed. Such a decision will likely involve the regulatory agencies, the property owner, the party responsible for the spill, and other stakeholders such as neighbors, fishermen, and hunters. The decision making process would consider human and ecological risks of no action balanced against the damage which would be caused by entry to the marsh for remedial efforts. If human health risk is found to be the controlling factor, a decision might be based upon the concentration of oil components found in the marsh soil as a result of the spill. Assuming the Louisiana Department of Environmental Quality has a significant technical input in the decision, the RECAP (LDEQ, 1998) guidance would likely be used to set this remedial standard based upon the concentration of TPH and TPH in various fractions. These concentrations are shown in Table 4.1.

Other states using a risk based corrective action program such as that in ASTM E1739 (1996) would likely use a similar approach.

4.2 Degree of Remediation Required and Applicability of Biodegradation

The difference between the remedial standard and the present condition is the amount of remediation needed. In a typical terrestrial spill, remedial efforts may consist of removal and disposal of contaminated soil. Removal of impacted marsh soil is a last resort option since it would damage the marsh. Another possible, but not preferred option, is washing the oil off the marsh surface. Such action might successfully remove the oil, but the water pressure would severely

Table 4.1 Louisiana RECAP Remedial Standards

Compound	Screening Level mg/kg	MO-1 Level mg/kg
PAHs		
Acenaphthlene	400	4000
Benzo(a)pyrene	0.33	0.33
Chrysene	61	61
Dibenzo(a,h)anthracene	0.33	0.33
Indeno(1,2,3-cd)pyrene	0.61	0.61
Benzo(k)fluoranthene	6.1	6.1
Benzo(a)anthracene	0.61	0.61
Fluoranthene	260	2600
Fluorene	280	2800
Naphthalene	210	2100
Pyrene	220	2200
TPH Fractions		
TPH-G (C6-C12)	130	1300
TPH-D (C10-C20)	130	1300
TPH-O (C20-C28)	180	1800

damage the marsh. Gently flooding the marsh could also be used to float some of the oil off (Hoff et al, 1993), however, such actions would require human entry to the marsh with its attendant damage. Another possibility is burning the marsh to destroy the oil. Under the right seasonal and tidal conditions, this may be very effective. Obviously this method cannot be used if the fire and smoke cannot be controlled so as to not impact areas not requiring remediation.

The final alternative for remediation of the marsh is biodegradation. Bioremediation is not a no-action alternative, but rather a minimal action alternative chosen when a feasibility study shows it to be advantageous. The marsh is allowed to naturally degrade the crude oil, either with or without nutrient addition, until it reaches the remedial standard. Prior to the approval of this course of action, however, the regulatory authorities, would require assurance based on investigation that bioremediation is expected to result in attainment of the remedial standard in a satisfactory time frame. The regulatory authorities would also require sufficient monitoring to demonstrate that the bioremediation is progressing in a satisfactory manner, and finally to document that the remedial standard was met. During the progress of the remedial process, while concentrations remain above the remedial standard, the regulatory authorities, together with the landowner would enforce institutional controls to prevent an unacceptable degree of exposure to the oil. These institutional controls might consist of prohibiting access to the impacted area to hunters and fishermen or of minimizing the duration of exposure by visitors.

The value of this research for cases where nutrient addition does not enhance biodegradation is in the forecasting of the rate of degradation of the spilled oil and providing methods to monitor the progress of that degradation. In those cases where nutrients are found beneficial, this research assists by

providing guidance on application rates, delivery methods, and costs. The results of this research can be used to estimate the remaining degree of oil at various times in a *Spartina alterniflora* marsh impacted by sweet Louisiana crude oil. Similar data, as it becomes developed for other habitats and oil types, will allow estimation of biodegradation versus time in other spill instances.

After evaluation of the fate of the oil, a decision can be made with the regulatory agencies, the responsible party, the landowner, and any other stakeholders on whether biodegradation is likely to achieve the desired degree of remedial action in the desired time frame. The responsible party would then make an agreement with the regulatory agency on the scope and schedule of a monitoring plan to document progress (or the lack of progress) toward meeting this remedial goal.

4.3 Progress Monitoring

Assuming that bioremediation will be attempted, the responsible party should propose a plan of monitoring. The scope of the monitoring and its frequency should depend on the goals of the regulators and the responsible party. Figure 4.1 explains this more clearly. If the anticipated time frame for cleanup without addition of nutrients is acceptable, and there is little probability than any of the stakeholders will ever push for acceleration, then monitoring may concentrate solely on the constituents defining the remedial standard, i.e., TPH. The frequency of monitoring should be such that for at least one and preferably several milestones along the way, an assessment can be made to determine if progress toward attaining the remedial standards is being made. For instance if the kinetics indicate approximately one year to reach the remedial standard, sampling and analysis might be done either quarterly or possibly semiannually. If evaluation of

the kinetics shows that two years will be required, a minimal monitoring plan would probably incorporate semiannual sampling and analysis.

If, on the other hand, the responsible party or one of the other stakeholders is pushing for acceleration of the cleanup, the monitoring should include collection of data to more closely determine the kinetics of the remediation and the concentrations of nitrogen in the porewater. A minimum of the initial conditions and three progress sampling analyses are recommended for determining the rate parameter in a one parameter equation. Progress sampling might, therefore, be made at one month, two months, and four months and the degradation of the oil evaluated. Collection of porewater samples at these intervals should also be done and the samples analyzed for nitrate and ammonia. The oil samples should be analyzed for TPH and for the relevant compounds and hopane to monitor degradation on the basis of the compound to hopane ratio. An oil that was proven by the initial sampling to be high in alkanes and low in PAHs such as in this study might concentrate on the same compounds used in the field plots. If, however, the oil had significant PAHs, they should also be analyzed.

At least four randomly chosen samples should be taken of the impacted area at each sampling event. The average TPH and standard deviation should be determined at each event. The compound to hopane ratio for each compound should be determined in each sample. The sum of the compounds to hopane ratio should also be determined and the average and standard deviation of the sum of the compounds to hopane ratio plotted versus time and compared to the most applicable previous degradation kinetics for the site conditions. The porewater ammonia concentration should also be compared to the best existing data for similar situations. A judgement can then be made as to whether the oil is degrading as fast as expected, and, if not, whether a nutrient shortage appears to

be the cause. The comparison between the expected kinetics in the absence of nutrient shortage and the site determined kinetics can be used to negotiate with the regulatory authority and other stakeholders on whether to conduct a pilot study. If an individual compound in the soil has a sizeable enough concentration to influence the time to attainment of the remedial standard and its kinetics are appreciably different from the sum of the compounds to hopane kinetics then the evaluation should also be made with respect to that compound. The hypothetical scenario in Appendix H illustrates consideration of this data in making a decision on whether to conduct a pilot test.

If the site is significantly different from this research, i.e. different oil type, marsh type, vegetation, or application rate of oil, then the kinetics from the most similar documented site should be used. Initially there will be no such documentation of sites dissimilar to the research site, but over the years as this procedure is used a body of knowledge will be built up allowing this evaluation.

4.4 Work Plan Outline for Pilot Test of Nutrient Application

If the comparison of the spill site kinetics to this research, or to other more similar sites, shows that the degradation kinetics are significantly slower than non-nitrogen limited conditions, and time is of the essence to the regulatory authority, the responsible party, or one of the other stakeholders, a pilot test of nutrient application may be conducted. A work plan should be prepared and executed. The activities to be defined in the work plan include

- Definition of remedial area
- Location and frequency of sampling for RECAP standard
- Location and frequency of sampling for porewater and soil nutrients
- Location and frequency of sampling for degradation kinetics
- Fingerprint of spill oil

- Compounds to be monitored for degradation kinetics
- Evaluation of degradation kinetics
- Selection of nutrient applications
- Application rates
- Application methods
- Criteria for reapplication of nutrients
- Health and safety planning
- Report format, frequency, and recipients

Depending on the results of the pilot test, full scale field application of nitrogen may be implemented. A hypothetical scenario of a spill which progresses through a pilot test and into consideration of full scale field application of nutrients is presented in Appendix H.

4.5 Work Plan Outline for Full Scale Application of Nutrients

If the pilot tests indicates that nutrient application will significantly speed the biodegradation and either the potential costs savings or other non-monetary motivation by the regulatory authorities or other stakeholders favor its implementation, a full scale application of nutrients may be done.

Once again the first step should be preparation and approval of a work plan. The work plan should include:

- Definition of remedial area
- Selection of nutrient
- Calculation of application rate
- Method of nutrient application
- Cost estimating and budgets
- Criteria for reapplication of nutrients
- Location and frequency of sampling for RECAP standard

- Location and frequency of sampling for porewater and soil nutrients
- Location and frequency of sampling for degradation kinetics
- Compounds to be monitored for degradation kinetics
- Evaluation of degradation kinetics
- Health and safety planning
- Reporting requirements

Most of the above items have been fully covered in earlier sections of this dissertation. Two items, application method and cost, demand fuller discussion.

Application of the fertilizer in the marsh will likely be made aerially. Inquiries were made during this research into a means to disperse granular fertilizer in an even manner a minimum of 150 feet. This distance was selected since the writer anticipates that many spills will be linear next to an open water body, with the lateral extent controlled by very minor relief. A dispersal device mounted on a boat could, therefore, apply the fertilizer to oil so distributed. No such fertilizer dispersal equipment or contractors were located. Several crop dusters were contacted, however, and the aerial application of a granular material is a routine, although costly operation. Development of the technology has advanced to the degree that control of flight paths is now done using global positioning systems (GPS). Consideration was also given dispersal of the fertilizer in a water stream, however, in light of the high solubility of ammonium nitrate and its rapid dissipation in the marsh, the writer recommends application in a granular form at low tide to allow a chance to diffuse into the marsh sediment prior to the next tidal cycle.

The cost of application of the nutrients will exceed the cost of the fertilizer itself if ammonium nitrate is used, as can be easily seen in Table 4.2. Depending on the location of the nearest airstrip, one can make calculations as to whether it is more cost effective to use an airplane with a larger payload but a greater

Table 4.2 Unit Costs for Work Items in an Engineered Bioremediation

Item	Unit	Unit Cost
Consultant Labor		
Jr. Engr/Scientist	man hour	$55.00
Sr Engr/Scientist	man hour	$95.00
Analytical (normal turnaround)	each	
TPH (by RECAP fractions)	each	$220.00
Nitrate	each	$15.00
Ammonia	each	$25.00
Materials		
Ammonium nitrate fertilizer	pound	$0.14
Meister time release urea	pound	$0.68
Crop Duster (2000# payload)	Hour	$600.00
Crop Duster (assumes 2000# payload, 40 minute round trip)	pound of payload	$0.20
Helicopter (800-1000# payload)	Hour	$1,000.00
Pickup Truck w/ fuel	Day	$100.00

distance to the landing strip and consequently longer travel time, or to deliver the fertilizer to a much closer helicopter accessible staging area. The hourly price of the helicopter is greater and the payload is less, but for a long distance to an air strip this may be more cost effective. It should be noted that aerial distribution by helicopters is not considered by the writer a well developed technology. Suppliers indicated they would drop granular fertilizers using a bucket. Application by airplane, however, has been accomplished over the rice fields of southwest Louisiana for decades.

Appendix H provides a scenario which illustrates the budgeting considerations conducted as part of the full scale work plan.

5. Conclusions and Recommendations

5.1 Technical Feasibility

The engineering management of bioremediation in a salt marsh is technically feasible. A program of monitoring the progress of the degradation has been demonstrated in the field during this study. The monitoring procedures used would be the same, plus the analysis for TPH, in a full scale oil landfall in the marsh.

As part of the engineered management of biodegradation, nutrients might be applied, if the application was indicated to be of benefit. Application of the nutrients was found to be technically feasible.

The types of nutrients to be applied are readily available. Two types of commercially available nitrogen fertilizers were used. Both are in granular form and readily available although the Meister time release urea is much more expensive than the ammonium nitrate. Based on the expense and no evidence of its superiority in either the mesocosms or the field plots, the time release urea is not recommended at this time. Ammonium nitrate will provide the nitrogen at less cost.

While application of nitrogen was not of benefit in the field plots, its use in the mesocosms confirms that an application rate for ammonium nitrate of 171 g/square meter is appropriate. This rate was significantly superior to the control mesocosm at 0.10 significance (although not at 0.05 significance).

The main difference between the techniques used in this research and in a full scale application will be the delivery method for the granular fertilizer. Application by airplane is recommended since crop dusting is a well developed technology and contractors are readily available. The Louisiana Department of

Natural Resources has used contractors to aerially apply seed and fertilizer to barrier islands off the Louisiana coast (Bahlinger, 1998).

5.2 Cost Feasibility

Unit costs for the various items involved in monitoring an oil spill once it makes landfall and in applying nutrients are presented in Table 4.2. The three biggest impediments in the path of nutrient application at this time are : 1) the lack of proven benefit in the subject study, 2) the high cost of delivery of the nutrients, and 3) the lack of monetary motivation to accelerate the remediation.

Previous chapters have noted that in this particular marsh, oil type, application rate, season etc., the fertilized plots did not degrade oil significantly faster than the control. A cost benefit analysis reaches a swift and unfavorable conclusion with no quantifiable benefit. But, since Louisiana sweet crude spilled in late summer making landfall in *S. alterniflora* is not the only possible scenario, we continue the discussion.

Table 4.2 shows the unit costs of various items. It will be noted that the cost of delivering the fertilizer to the marsh far exceeds the cost of the fertilizer itself. The rate of washout is also rapid so several applications will be needed. A scenario in Appendix H better illustrates how all the unit costs go into the total cost of applying fertilizer and monitoring the progress of the bioremediation, and give some idea of the total cost. A sizeable benefit will be required to outweigh this cost in a cost benefit analysis.

The last factor is the lack of monetary motivation to speed the bioremediation. The scenario in Appendix H shows the cost of accelerating the remediation in a hypothetical case where nutrient application was found of benefit. The benefit to the responsible party of avoiding a few periodic monitoring visits and periodic reports is far outweighed by the cost of the fertilizer application.

Unless some cost similar to liquidated damages in a construction contract exists, there is little to motivate the responsible party to speed the cleanup. Threats of a civil suit by the property owner for the loss of enjoyment of his property may provide some such motivation, however, judgements for items other than personal injury are usually not of a magnitude to motivate a costly acceleration of the cleanup, and if institutional controls were exercised while the site was impacted no personal injury should occur. While a suit may be filed as a result of damages caused by the oil spill, the writer doubts whether, in the absence of proving negligence in conducting the cleanup, the shortening of time to reach the remedial standard caused by nutrient application would appreciably affect the amount of the judgement in such a suit. The main motivation will likely have to come from insistence by the regulatory authority that nutrients, if shown to be beneficial, be applied, even if the quantifiable costs and benefits do not support nutrient application.

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Appendix A Procedure for Extraction of Oil from Marsh Samples

The marsh soil was removed from the core holding it by extrusion under its own weight onto a sheet of aluminum foil, while being maintained in a vertical position. The upper 2 inches was sliced from the core and placed on a separate sheet of foil, while the lower portion of marsh soil, into which the oil had not seeped was disposed. The upper two inches of marsh sample with oil was then weighed and homogenized by kneading by latex gloved hands until a uniform consistency and color was achieved. Three individual replicates were then selected from the soil for extraction. Each replicate came from a separate area of the sample and consisted of about 5 grams of soil (wet weight) to which 10 ml of an acetone/hexane (50/50) mixture was added in a 50 ml Teflon centrifuge tube. The actual weight of the soil was determined prior to placing in the centrifuge tube.

The procedure for soils from field plots involved homogenization of the entire (about 1 liter) sample. About 10 to 20 grams of marsh soil was then added to 20 ml of acetone/hexane mixture in a Teflon centrifuge tube. A greater volume of soil was used in the field plots than in the mesocosms due to an anticipated lesser amount of oil remaining with each successive sampling event.

Each centrifuge tube was labeled and shaken for at least 3 hours to extract the oil from the marsh soil. After shaking, each tube was centrifuged. The liquid was separated into aqueous and nonaqueous phases using separatory bulbs. The aqueous phase was disposed. The nonaqueous phase was poured through sodium sulfate to scavenge out any remaining water and placed in individual 20 ml vials. The contents of each vial was evaporated to a volume of 5 ml. One ml of this extract was placed in a GC/MS autosampler vial

and 10 μl of semivolatile internal standard added. The extract was then analyzed on the GC/MS.

Appendix B Pour Plate Technique for Determining Number of Microbes

Soil samples for microbial counts were taken at the same time homogenized soil was taken for oil extraction or ammonia extraction.

Prior to beginning, dilution tubes with dilution water were autoclaved. The dilution water consisted of deionized water with 8 grams per liter sodium chloride. Sufficient dilution tubes for 10 serial dilutions of each soil sample each with 9 ml of dilution water (10 ml in first dilution) were prepared and autoclaved.

Approximately one gram (wet weight) was weighed and placed into the first dilution tube. The tube was shaken and 1 ml of its contents transferred to the second dilution tube. The same procedure was repeated from the second to the third, from the third to the fourth and so on until 10 serial dilutions each one tenth the concentration of the previous were prepared.

Pour plate petri dishes were obtained for three serial dilutions of each soil sample. Agar was prepared by mixing in one liter of deionized water 15 grams of agar and 37.4 grams of marine broth (Bushnell Haas, Difco Laboratories, Detroit, Michigan). One ml of each desired dilution was pipeted into a petri dish. Agar at about 40 degrees C was then poured into the dish, swirled gently for full bottom coverage, and the dish covered.

Once solidified, the petri dishes were stored, oriented as poured until any colonies of microorganisms developed. After about three days to one week the number of colony forming units were counted on the plate for each sample which has between 30 and 200 CFUs. The number of CFUs were expressed as CFUs per gram dry weight based on the degree of dilution in the counted plate, the actual weight of wet soil used, and the water content of the soil.

Appendix C Sheen Screen Technique for Determining Most Probable Number of Oil Degrading Microbes

The sheen screen technique started in the same manner as the pour plate method, with the first dilution made from approximately one gram wet weight of soil in 10 ml of dilution water. Dilutions were, however, done in 4 by 6 segmented trays with four columns of six cells each. Each cell had a 2 ml capacity. Four replicates were done of each dilution. The first row of cells had 1 ml of dilution liquid and 1 ml of the first serial dilution from the dilution tubes. The second row had 1.8 ml of dilution liquid and 0.2 ml from the first row. The third row had 1.8 ml of dilution liquid and 0.2 ml from the second row, and so on, resulting in the concentration of initial innoculum in a row of cells being one-tenth of the concentration in the previous row.

Dilution liquid consisted of Buschnell Haas broth made of 37.4 g marine broth, 1 g KH_2PO_4, 1 g K_2HPO_4, 1 g ammonium nitrate, 0.2 g $MgSO_4*7H_2O$, 0.5 g $FeCl_3*6H_2O$, and 0.2 g $CaCl_2*2H_2O$ in 1 liter of deionized water. The dilution liquid was autoclaved at 121 degrees C at 15 psig for 30 minutes and allowed to cool before adding the innoculum.

Each of the 24 segmented cells received 50 microliters of oil. The cells were covered and allowed to sit for one to two weeks. Cells were scored for the presence of oil degrading bacteria by the breaking up of the oil sheen on the cell surface. The Thomas equation (Metcalf & Eddy, Inc., 1991) for approximation of most probable number was used.

Appendix D GC/MS Details and Oil Components Analyzed

Crude oil analyses were performed using a Hewlett-Packard 5890 gas chromatograph coupled with a 5972A mass selective detector (GC/MS) in the selected ion monitoring mode. Operating conditions of the chromatograph were:

- 1 μl splitless injection
- HP-5 capillary column 30 m long, 0,53 um diameter
- Injector at 300 degrees C
- Oven temperature initially at 55 degree C for 3 minutes, ramped up to 310 degree C at 6 degree C per minute.
- GC.MS interface held at 280 degree C.

Internal standards were the following deuterated compounds: 1,4 dichlorobenzene-d4, naphthalene-d8, acenaphthene-d8, phenanthrene-d10, and chrysene-d12. Quantitation was performed using a 5-point calibration curve referenced to the internal deuterated standards. The deuterated standards were obtained from Supelco, Inc. Calibration standards for the compounds monitored were obtained from AccuStandard (standards DRH-004S-5X and DRH-005S-10X).

Tables D.1 and D.2 list the compounds quantitated in the GC/MS runs for the mesocosms and the field plots respectively.

Table D.1 Compounds Quantitated in the Mesocosm Samples

Ion m/z	Compound	Structure	Retention Time - minutes
85.05	Decane	$C_{10}H_{22}$	6.6
85.05	Undecane	$C_{11}H_{24}$	9.1
128.1	Naphthalene	$C_{10}H_8$	10.9
85.05	Dodecane	$C_{12}H_{26}$	11.6
85.05	Tridecane	$C_{13}H_{28}$	13.9
85.05	Tetradecane	$C_{14}H_{30}$	16.1
152	Acenaphthylene	$C_{12}H_8$	16.7
153	Acenaphthene	$C_{12}H_{10}$	18
85.05	Pentadecane	$C_{15}H_{32}$	18.2
166.1	Fluorene	$C_{13}H_{10}$	19.5
85.05	Hexadecane	$C_{16}H_{34}$	20.1
85.05	Heptadecane	$C_{17}H_{36}$	22
85.05	Pristane	$C_{17}H_{36}$	22.1
178.05	Phenanthrene	$C_{14}H_{10}$	23
178.05	Anthracene	$C_{14}H_{10}$	23
85.05	Octadecane	$C_{18}H_{38}$	23.7
85.05	Eicosane	$C_{20}H_{42}$	27
202.04	Fluoranthene	$C_{15}H_{10}$	27.6
202.05	Pyrene	$C_{16}H_{10}$	28.3
85.05	Tetracosane	$C_{24}H_{50}$	32.8
228.1	Benzo (a) anthracene	$C_{18}H_{12}$	33.2
228.1	Chrysene	$C_{18}H_{12}$	33.2
252.1	Benzo (b) fluoranthene	$C_{19}H_{12}$	38.28
252.1	Benzo (k) fluoranthene	$C_{19}H_{12}$	38.38
85.05	Octacosane	$C_{28}H_{58}$	37.7
252.1	Benzo (a) pyrene	$C_{20}H_{12}$	38.2
278.1	Dibenzo (a,h) anthracene	$C_{22}H_{14}$	42.82
276.1	Benzo (g,h,i) perylene	$C_{22}H_{12}$	42.7
85.05	Dotriacontane	$C_{32}H_{66}$	42
276.1	Indeno (1,2,3-cd) pyrene	$C_{22}H_{12}$	43.37
191	Hopane		41.2
85.05	Hexatriacontane	$C_{36}H_{74}$	45.8
85.05	Tetratetradecane	$C_{44}H_{90}$	51.46

All alkanes used are straight chained (n-) with the exception of pristane.
Actual retention times may differ from those presented depending on matrix.

Table D.2 Compounds Quantitated in the Field Plot Samples

Ion m/z	Compound	Structure	Retention Time - minutes
	Alkanes		
85.05	Decane	$C_{10}H_{22}$	6.6
85.05	Undecane	$C_{11}H_{24}$	9.1
85.05	Dodecane	$C_{12}H_{26}$	11.6
85.05	Tridecane	$C_{13}H_{28}$	13.9
85.05	Tetradecane	$C_{14}H_{30}$	16.1
85.05	Pentadecane	$C_{15}H_{32}$	18.2
85.05	Hexadecane	$C_{16}H_{34}$	20.1
85.05	Heptadecane	$C_{17}H_{36}$	22
85.05	Pristane	$C_{17}H_{36}$	22.1
85.05	Octadecane	$C_{18}H_{38}$	23.7
85.05	Phytane	$C_{18}H_{38}$	23.9
85.05	Eicosane	$C_{20}H_{42}$	27
85.05	Docosane	$C_{22}H_{42}$	30
85.05	Tetracosane	$C_{24}H_{50}$	32.8
85.05	Hexacosane	$C_{26}H_{54}$	35.3
85.05	Octacosane	$C_{28}H_{58}$	37.7
85.05	Triacontane	$C_{30}H_{62}$	39.9
85.05	Dotriacontane	$C_{32}H_{66}$	42
85.05	Tetratriacontane	$C_{34}H_{70}$	44
85.05	Hexatriacontane	$C_{36}H_{74}$	45.8
85.05	Octatriacontane	$C_{38}H_{78}$	48
	PAHs		
128.1	Naphthalene	$C_{10}H_8$	10.9
152	Acenaphthylene	$C_{12}H_8$	16.7
153	Acenaphthene	$C_{12}H_{10}$	18
166.1	Fluorene	$C_{13}H_{10}$	19.5
184	Dibenzothiophene		22.45
178.05	Phenanthrene	$C_{14}H_{10}$	23
178.05	Anthracene	$C_{14}H_{10}$	23
202.04	Fluoranthene	$C_{15}H_{10}$	27.6
202.05	Pyrene	$C_{16}H_{10}$	28.3
228.1	Benzo (a) anthracene	$C_{18}H_{12}$	33.2
228.1	Chrysene	$C_{18}H_{12}$	33.2
252.1	Benzo (b) fluoranthene	$C_{19}H_{12}$	38.28
252.1	Benzo (k) fluoranthene	$C_{19}H_{12}$	38.38
252.1	Benzo (a) pyrene	$C_{20}H_{12}$	38.2
278.1	Dibenzo (a,h) anthracene	$C_{22}H_{14}$	42.83
276.1	Benzo (g,h,i) perylene	$C_{22}H_{12}$	42.7
276.1	Indeno (1,2,3-cd) pyrene	$C_{22}H_{12}$	43.37
191	Hopane		41.2

All alkanes used are straight chained (n-) with the exception of pristane and phytane.
Actual retention times may differ from those presented depending on matrix.

Appendix E Fractions of Compounds Remaining at Various Points in Time During Field Plot Phase

		Plot					
Compound	Day	A2	B2	C2	D2	E2	F2
Undecane	0	1	1	1	1	1	1
Undecane	21	1.53365477	1.27791998	#VALUE!	1.93913696	2.01190635	2.41995465
Undecane	42	1.30778372	0.94594313	0.48758779	0.81916049	3.04141092	1.98465964
Undecane	75	0.71691469	0.6311313	0.75847542	1.01831152	0.42920154	0.69133807
Undecane	97	0.14960492	0.73372803	0.46181836	1.05548006	0.77381014	1.04715447
Undecane	137	0.29073773	0.67155227	0.16562717	0.97357143	2.98601145	0.65333176
Undecane	158	0.0443519	0.70263786	0.0365827	1.2668107	1.26809245	0.93204326
Undecane	181	0.6712866	0.56803472	0.15911666	0.3951184	0.52887663	0.55451601
Dodecane	0	1	1	1	1	1	1
Dodecane	21	1.13408995	1.07616973	#DIV/0!	1.31556869	1.02362169	1.47113463
Dodecane	42	1.19988345	0.81157216	0.5674177	0.76536222	1.30167993	1.3797332
Dodecane	75	0.66551197	0.59827356	0.67325236	0.85603222	0.22314513	0.67325848
Dodecane	97	0.09170494	0.66133929	0.46081044	0.90016304	0.3504896	1.00837097
Dodecane	137	0.2149915	0.64592663	0.17729739	0.90625	1.5736524	0.59283807
Dodecane	158	0.0724983	0.65941596	0.05019143	1.07977376	0.6271984	0.99371403
Dodecane	181	0.63593256	0.53605691	0.17007294	0.37001237	0.31608815	0.38766054
Tridecane	0	1	1	1	1	1	1
Tridecane	21	0.95853423	1.07201269	#DIV/0!	1.20744313	0.90383996	1.22666667
Tridecane	42	1.00984106	0.81581903	0.63121352	0.72579665	0.93870707	1.14465669
Tridecane	75	0.57461044	0.61457864	0.65175938	0.79029244	0.19733404	0.65725722
Tridecane	97	0.07597125	0.69685337	0.4523935	0.88976364	0.25475231	0.9769606
Tridecane	137	0.1514259	0.61369903	0.19894575	0.87303665	1.08865001	0.58749602
Tridecane	158	0.05543988	0.64093313	0.05375417	0.92528763	0.46763069	0.89321483
Tridecane	181	0.53874564	0.5150208	0.14122208	0.34072421	0.25146787	0.30393335
Tetradecane	0	1	1	1	1	1	1
Tetradecane	21	0.86201159	1.08246059	#DIV/0!	1.11247726	1.01653247	1.13940819
Tetradecane	42	0.90050885	0.80237855	0.64136319	0.63132598	0.90855882	1.02654183
Tetradecane	75	0.53878405	0.65726181	0.62767086	0.73015943	0.22565513	0.64413534
Tetradecane	97	0.0896364	0.76505175	0.48591234	0.82549303	0.29035571	0.97143431
Tetradecane	137	0.15484152	0.67014505	0.21563002	0.77085605	1.09669008	0.61730441
Tetradecane	158	0.0803114	0.92856252	0.08668117	0.86149691	0.48457383	0.98104373
Tetradecane	181	0.49239537	0.57908447	0.15117834	0.35262587	0.26382067	0.30326212
Pentadecane	0	1	1	1	1	1	1
Pentadecane	21	0.86823217	1.25154637	#DIV/0!	1.21966074	1.14900032	1.22442002
Pentadecane	42	0.83734644	0.81916015	0.70706089	0.70224602	0.81571339	0.9657546
Pentadecane	75	0.47121532	0.66931092	0.55896947	0.67543284	0.23874538	0.54971574
Pentadecane	97	0.15895522	0.87398516	0.48653215	0.88400023	0.3082131	0.88605378
Pentadecane	137	0.15107511	0.65102473	0.2431235	0.78436194	0.95677843	0.53550868
Pentadecane	158	0.1426453	0.66640265	0.1187044	0.88882249	0.47489522	0.81295331
Pentadecane	181	0.42584228	0.61637454	0.16294747	0.36603557	0.281445	0.30007105

Compound	Day	G2	H2	I2	J2	A3	B3
Undecane	0	1	1	1	1	1	1
Undecane	21	0.25811966	1.36400799	0.77419355	#VALUE!	0.25264177	#DIV/0!
Undecane	42	1.02459712	0.68126478	2.78924856	0.94315556	0.29069348	1.31185106
Undecane	75	0.19018038	0.33973022	0.84792982	0.50455127	2.37335979	0.90636244
Undecane	97	1.23178622	2.08210313	0.49561344	0.26612636	0.64451761	0.45203047
Undecane	137	1.05578355	0.48522202	0.16125838	0.1506541	0.86636341	0.73424077
Undecane	158	1.04417091	0.2331015	0.09122891	0.76758981	0.06145997	0.62598227
Undecane	181	0.2344493	0.85001472	0.17188252	0.0388821	0.34647857	0.49092033
Dodecane	0	1	1	1	1	1	1
Dodecane	21	0.22734739	1.23881678	0.53513514	#VALUE!	0.29474873	#DIV/0!
Dodecane	42	0.75842064	0.82248275	1.66171615	0.84873436	0.47334848	1.02872291
Dodecane	75	0.22454798	0.28143422	0.72317078	0.45533106	1.78581796	0.76603497
Dodecane	97	0.83665931	1.17328191	0.51905462	0.35492376	0.08485812	0.43061044
Dodecane	137	0.75275423	0.37419566	0.15353225	0.1482072	0.81064779	0.65387736
Dodecane	158	0.83502158	0.24250075	0.06879153	0.78774746	0	0.59272119
Dodecane	181	0.19398385	0.63444263	0.14400968	0.06453159	0.43215328	0.42914385
Tridecane	0	1	1	1	1	1	1
Tridecane	21	0.25842191	1.07702717	0.41351351	#VALUE!	0.506917	#DIV/0!
Tridecane	42	0.73905366	0.72686384	1.08586206	0.83972853	0.66452648	0.96380471
Tridecane	75	0.24254736	0.24002545	0.56945717	0.48225881	1.51197388	0.74487497
Tridecane	97	0.7923102	0.66643933	0.47580007	0.43390809	0.82614743	0.38151174
Tridecane	137	0.70532491	0.27070381	0.11566096	0.16639812	0.74006024	0.60573976
Tridecane	158	0.82113194	0.21109482	0.04203927	0.76818215	0.03461538	0.54995371
Tridecane	181	0.15854153	0.42318193	0.06429004	0.068732	0.42541197	0.40937592
Tetradecane	0	1	1	1	1	1	1
Tetradecane	21	0.29107766	1.01056134	0.36521739	#VALUE!	0.68774704	#DIV/0!
Tetradecane	42	0.68469497	0.72022706	0.86942136	0.88587382	0.68120424	1.02438672
Tetradecane	75	0.23886982	0.28439904	0.83316904	0.49760318	1.16722716	0.8182724
Tetradecane	97	0.7435727	0.62351047	0.54871488	0.5405762	0.13575766	0.42411711
Tetradecane	137	0.64977195	0.28213318	0.10538097	0.19706672	0.68004702	0.65602122
Tetradecane	158	0.74525053	0.23162571	0.07377642	0.86351196	0.05712946	0.57248193
Tetradecane	181	0.15317541	0.36496087	0.11583387	0.1001067	0.36623443	0.43076123
Pentadecane	0	1	1	1	1	1	1
Pentadecane	21	0.3585721	1.1171875	0.37570093	#VALUE!	0.89489976	#DIV/0!
Pentadecane	42	0.71244759	0.67359004	0.74269031	0.80751174	0.66121952	0.88375449
Pentadecane	75	0.24929121	0.28151603	0.49242544	0.47330765	0.97440852	0.67997832
Pentadecane	97	0.76223543	0.54143116	0.5444414	0.52715609	0.78723796	0.42681935
Pentadecane	137	0.60882713	0.26534825	0.13166466	0.20215751	0.57776891	0.62667402
Pentadecane	158	0.76394429	0.23202233	0.09779398	0.78153092	0.08466172	0.63974721
Pentadecane	181	0.21178745	0.41337025	0.1529502	0.13281064	0.39409503	0.44472207

Compound	Day	C3	D3	E3	F3	G3	H3
Undecane	0	1	1	1	1	1	1
Undecane	21	0.88342697	1.30195918	1.06400665	1.18904876	#VALUE!	2.29604544
Undecane	42	1.66813662	0.4709164	0.58814183	0.70134143	0.80447942	1.81929479
Undecane	75	1.09854123	0.29576478	0.60075237	0.50154117	0.28969523	0.68198054
Undecane	97	0.71364918	0.91878095	0.22235381	0.29739953	0.77447552	3.26499725
Undecane	137	0.86533094	0.51022243	0.37189502	0.42684856	1.11831218	0.52957274
Undecane	158	0.47828848	0.27198474	0.50741445	0.83943873	0.44158692	1.98386354
Undecane	181	0.06970714	0.24982302	0.04851366	0.13226267	0.14975576	0.89161794
Dodecane	0	1	1	1	1	1	1
Dodecane	21	0.6702509	1.06069947	0.91868405	0.98753296	#DIV/0!	1.47975045
Dodecane	42	1.1980937	0.47347165	0.65434831	0.64490513	0.81648657	0.83803916
Dodecane	75	0.92980013	0.31543896	0.78417366	0.5024362	0.35709579	0.43744298
Dodecane	97	0.62117141	0.81781466	0.29324938	0.32734791	0.63113976	1.29552403
Dodecane	137	0.74670474	0.61144376	0.44256855	0.41013222	0.87807335	0.30608656
Dodecane	158	0.48658197	0.28906715	0.5510954	0.75757137	0.56549489	1.06338448
Dodecane	181	0.10376953	0.24324997	0.07120508	0.12418703	0.13075689	0.33755353
Tridecane	0	1	1	1	1	1	1
Tridecane	21	0.63909774	1.01302083	0.92356186	1.0025774	#DIV/0!	1.16822598
Tridecane	42	0.95634662	0.47184259	0.67244258	0.66391844	0.75213979	0.61064562
Tridecane	75	0.86524447	0.34623831	0.85020417	0.5577089	0.36604196	0.37843488
Tridecane	97	0.53632469	0.75098611	0.32842335	0.34111417	0.50462212	0.91686317
Tridecane	137	0.65037481	0.65366673	0.4477298	0.40962337	0.76432289	0.26071316
Tridecane	158	0.44981083	0.27855256	0.54026352	0.71173941	0.57970254	0.73270165
Tridecane	181	0.10624952	0.22977331	0.07707372	0.13785036	0.12384621	0.23734826
Tetradecane	0	1	1	1	1	1	1
Tetradecane	21	0.63387784	1.03152194	0.89541417	0.96175851	#DIV/0!	0.9983523
Tetradecane	42	0.87914823	0.53561656	0.6674635	0.69528597	0.7630674	0.54160741
Tetradecane	75	0.87278891	0.37423668	0.9197373	0.75208377	0.35284824	0.5659768
Tetradecane	97	0.53646622	0.13220915	0.346042	0.3500738	0.50978136	0.81705668
Tetradecane	137	0.66749815	0.71989425	0.5596272	0.41669301	0.92130587	0.23435755
Tetradecane	158	0.48764566	0.32410303	0.48931085	0.7480051	0.55002725	0.67180695
Tetradecane	181	0.12924866	0.25911902	0.00547167	0.2414211	0.15229592	0.29489943
Pentadecane	0	1	1	1	1	1	1
Pentadecane	21	0.74174528	1.08863004	1.06321839	1.09573101	#DIV/0!	1.07269039
Pentadecane	42	0.85773501	0.48408889	0.65974544	0.68060401	0.7476614	0.52484673
Pentadecane	75	0.79574352	0.36081881	0.87124398	0.57382387	0.37676047	0.38579128
Pentadecane	97	0.58527825	0.90700171	0.4101555	0.39845737	0.47848785	1.01104824
Pentadecane	137	0.65020197	0.65321645	0.54058908	0.45214124	0.71977659	0.30735356
Pentadecane	158	0.51011747	0.32885428	0.97676868	0.77682484	0.56872898	0.70871063
Pentadecane	181	0.14631924	0.26139699	0.14457475	0.22563449	0.16307068	0.26576358

Compound	Day	I3	J3	A4	B4	C4	D4
Undecane	0	1	1	1	1	1	1
Undecane	21	not enuf	1.26514116	#VALUE!	0.59594162	0.16905258	1.1388998
Undecane	42	0.34200246	0.67310244	0.61021818	0.79494091	0.80338292	0.76465064
Undecane	75	0.69880309	0.31130205	#DIV/0!	1.04649824	0.35316781	0.62647754
Undecane	97	0.5459934	0.51909674	1.27895763	0.12464874	0.76319371	0.30823565
Undecane	137	0.12824119	0.48289904	0.50648872	0.19407008	0.08252719	0.10508656
Undecane	158	0.0673525	0.50940223	#DIV/0!	0.07991121	0.25059559	0.18318279
Undecane	181	0.06473969	0.54089295	0.32994862	0.50409958	0.18672032	0.37298687
Dodecane	0	1	1	1	1	1	1
Dodecane	21	not enuf	0.9404267	#VALUE!	0.56936737	0.3051965	1.02059899
Dodecane	42	0.336789	0.74529506	0.60478799	0.85084034	0.86423117	0.78346329
Dodecane	75	0.44170416	0.35656389	#DIV/0!	0.96370887	0.53088803	0.68083821
Dodecane	97	0.30979343	0.5334504	0.11762003	0.1689612	0.91139216	0.37307776
Dodecane	137	0.08791298	0.44627404	0.43137178	0.25997899	0.15196898	0.15473271
Dodecane	158	0.0791255	0.54260953	#DIV/0!	0.11211073	0.33571615	0.26535014
Dodecane	181	0.04880597	0.44819739	0.18720403	0.42616261	0.23340338	0.3124583
Tridecane	0	1	1	1	1	1	1
Tridecane	21	not enuf	0.86712913	#VALUE!	0.62998704	0.41236356	0.97527889
Tridecane	42	0.33915244	0.75286073	0.67005137	0.81197047	0.84673708	0.78678867
Tridecane	75	0.34846981	0.41288152	#DIV/0!	0.95996895	0.66948436	0.74103343
Tridecane	97	0.21350151	0.59656542	0.77934491	0.15129121	0.91177363	0.38448661
Tridecane	137	0.05878196	0.44925792	0.44990967	0.29811887	0.18251693	0.19060342
Tridecane	158	0.07633284	0.58714597	#DIV/0!	0.13093848	0.40961447	0.30660132
Tridecane	181	0.0400209	0.4542749	0.19177319	0.44512609	0.30751611	0.34818721
Tetradecane	0	1	1	1	1	1	1
Tetradecane	21	not enuf	0.82613587	#VALUE!	0.72844296	0.49824846	0.94697673
Tetradecane	42	0.40281394	0.71219109	0.76103554	0.80276266	0.83663526	0.78022648
Tetradecane	75	0.35301293	0.61622189	#DIV/0!	0.99565975	0.71001607	0.7765331
Tetradecane	97	0.22343181	0.65540055	0.18854603	0.21743885	0.99165134	0.38761251
Tetradecane	137	0.08112001	0.50121367	0.1505033	0.07660214	0.06100744	0.0553156
Tetradecane	158	0.10429195	0.61351447	#DIV/0!	0.16327653	0.43453801	0.3514698
Tetradecane	181	0.07135509	0.63076354	0.21380671	0.48749817	0.35568329	0.36112797
Pentadecane	0	1	1	1	1	1	1
Pentadecane	21	not enuf	0.99355308	#VALUE!	0.87906086	0.61168093	1.10693705
Pentadecane	42	0.38760278	0.68996089	0.84347565	0.78637528	0.7810127	0.7808197
Pentadecane	75	0.30669016	0.44274314	#DIV/0!	0.86914744	0.66110342	0.71046012
Pentadecane	97	0.22656019	0.6717348	0.90185586	0.25591905	1.20188427	0.42838675
Pentadecane	137	0.10312822	0.48185768	0.46541549	0.37338883	0.24506378	0.24349043
Pentadecane	158	0.12611512	0.58185826	#DIV/0!	0.18151261	0.44786293	0.39079351
Pentadecane	181	0.07830176	0.50703921	0.20796898	0.44959257	0.39885484	0.37198576

Compound	Day	E4	F4	G4	H4	I4	J4
Undecane	0	1	1	1	1	1	1
Undecane	21	0.56158336	0.9103996	1.5089056	1.65733288	#VALUE!	1.37935252
Undecane	42	0.73476957	1.24968658	0.58856214	0.62927941	0.42389976	0.46210925
Undecane	75	0.68882	0.89677602	0.48453531	0.26534244	0.257004	0.22091304
Undecane	97	0.54145595	0.82352941	0.49569754	1.18399015	0.58584381	0.16922811
Undecane	137	1.19728217	0.20354384	0.44276867	0.12393998	0.23494577	0.53170722
Undecane	158	0.18956534	0.58071559	0.24457143	0.57351455	0.5162797	0.52480121
Undecane	181	0.61167531	0.50448201	0.17921602	1.19722777	0.41081496	2.88021258
Dodecane	0	1	1	1	1	1	1
Dodecane	21	0.69664135	0.6279448	1.21918513	1.25726789	#VALUE!	0.94318182
Dodecane	42	0.70432816	0.90589479	0.65840506	0.67944943	0.46478209	0.46240949
Dodecane	75	0.6947824	0.73372396	0.46836892	0.31627031	0.2899826	0.24792876
Dodecane	97	0.53432271	0.66388387	0.52697249	0.91136601	0.08622445	0.21746725
Dodecane	137	0.94007836	0.19638801	0.44080165	0.14420585	0.25835813	0.38921905
Dodecane	158	0.25032444	0.54529639	0.25890739	0.56435008	0.5268001	0.50239234
Dodecane	181	0.34605165	0.18972707	0.06953881	0.2834031	0.09418605	0.33820835
Tridecane	0	1	1	1	1	1	1
Tridecane	21	0.86670958	0.61054703	1.11472267	1.16701903	#VALUE!	0.89042582
Tridecane	42	0.72204594	0.785109	0.68271054	0.67706245	0.49632643	0.47501216
Tridecane	75	0.68824454	0.704947	0.49672937	0.39635623	0.34987698	0.30089571
Tridecane	97	0.47785987	0.53747241	0.51767945	0.69687708	0.50735684	0.22015572
Tridecane	137	0.7547999	0.20219528	0.40878192	0.18377862	0.26934894	0.34331399
Tridecane	158	0.29646308	0.5648756	0.27787807	0.52965684	0.47734322	0.4906738
Tridecane	181	0.35356248	0.20868149	0.08178362	0.33992865	0.12522156	0.36865402
Tetradecane	0	1	1	1	1	1	1
Tetradecane	21	0.89509072	0.66235985	1.10048132	1.03639145	#VALUE!	0.83833572
Tetradecane	42	0.68456597	0.69894022	0.72951895	0.62591994	0.51675831	0.45672604
Tetradecane	75	0.66426117	0.67643597	0.53485051	0.40876446	0.55642271	0.32524165
Tetradecane	97	0.43674184	0.54567705	0.52855879	0.60134771	0.63946383	0.21164316
Tetradecane	137	0.66996354	0.22237452	0.47742212	0.21221401	0.31010836	0.34721036
Tetradecane	158	0.53347027	0.54415905	0.29374799	0.51736218	0.53332924	0.45684513
Tetradecane	181	0.3789598	0.24530368	0.12520993	0.32236408	0.14326892	0.3313436
Pentadecane	0	1	1	1	1	1	1
Pentadecane	21	1.11164134	0.87728996	1.26475521	1.17245571	#VALUE!	1.01319359
Pentadecane	42	0.69315978	0.69771871	0.71283171	0.58131323	0.49525753	0.49414358
Pentadecane	75	0.56631497	0.58702532	0.48014519	0.43143827	0.4048197	0.35315558
Pentadecane	97	0.49599573	0.50525522	0.53850436	0.59315789	0.83692982	0.21433887
Pentadecane	137	0.6547924	0.23289184	0.43875507	0.25094185	0.33042702	0.3518752
Pentadecane	158	0.39522584	0.51776067	0.29615781	0.49919424	0.52200541	0.46972549
Pentadecane	181	0.37483469	0.22793447	0.13191124	0.30790981	0.15629745	0.31214906

		Plot					
Compound	Day	A2	B2	C2	D2	E2	F2
Hexadecane	0	1	1	1	1	1	1
Hexadecane	21	0.92625412	1.26956444	#DIV/0!	1.25267246	1.15032609	1.2473545
Hexadecane	42	0.82485516	0.82265177	0.71843687	0.75407216	0.75397021	0.91331096
Hexadecane	75	0.50832289	0.61399893	0.5689336	0.70435815	0.26695596	0.56733912
Hexadecane	97	0.03818744	0.81877613	0.48319705	0.90586605	0.32134615	0.89444444
Hexadecane	137	0.17669603	0.65805054	0.25618237	0.81291528	0.85546506	0.55260978
Hexadecane	158	0.13585267	0.67914263	0.12787086	0.86340499	0.42551089	0.77481186
Hexadecane	181	0.43616219	0.60414412	0.1596081	0.37160588	0.26711843	0.297719
Heptadecane	0	1	1	1	1	1	1
Heptadecane	21	0.95633209	1.27564042	#DIV/0!	1.42945088	1.10972294	1.24227006
Heptadecane	42	0.7842755	0.8429148	0.72504536	0.87907848	0.71059682	0.87965432
Heptadecane	75	0.48504705	0.70245927	0.53950402	0.78276559	0.27781007	0.59235728
Heptadecane	97	0.14408222	0.2901208	0.51789355	1.04546713	0.32455839	0.91907785
Heptadecane	137	0.13763691	0.67278085	0.23073829	0.89931441	0.79978473	0.53773082
Heptadecane	158	0.09185944	0.16824281	0.12501435	0.93841628	0.39684799	0.74310975
Heptadecane	181	0.42089241	0.20545405	0.14024083	0.41244633	0.24835334	0.28729167
Pristane	0	1	1	1	1	1	1
Pristane	21	1.02470782	1.36536913	#DIV/0!	1.23417198	1.25780249	1.20952381
Pristane	42	0.96080421	1.00709567	0.96639296	0.89039184	0.77370433	0.9295302
Pristane	75	0.83150924	0.84599057	0.90269413	0.7916314	0.68607998	0.7918552
Pristane	97	1.1027994	1.27483679	1.18418912	1.19408791	1.11194939	1.16585366
Pristane	137	1.06418356	0.80712845	1.07246357	0.94243567	0.87179406	1.07539354
Pristane	158	0.9680315	1.04209147	0.78030759	1.08394199	0.83673505	1.05976096
Pristane	181	0.65460663	0.77854374	0.80145545	0.76872688	0.51677108	0.46851385
Octadecane	0	1	1	1	1	1	1
Octadecane	21	0.93028216	1.21954103	#DIV/0!	1.20010721	1.06045099	1.17346939
Octadecane	42	0.84514288	0.87820748	0.81764958	0.84289242	0.74839089	0.93995686
Octadecane	75	0.50970236	0.63340763	0.58167068	0.71311998	0.29875884	0.58633646
Octadecane	97	0.14181879	0.85914958	0.54210107	1.01093058	0.33554914	0.95365854
Octadecane	137	0.17498819	0.67547542	0.28407715	0.86892393	0.82723394	0.6084152
Octadecane	158	0.11678784	0.61353713	0.13673717	0.86693122	0.41333792	0.74615822
Octadecane	181	0.40012901	0.54311029	0.12884097	0.36221702	0.23660504	0.27208528
Phytane	0	1	1	1	1	1	1
Phytane	21	0.96742602	1.08412081	#DIV/0!	1.18631064	1.15764453	1.17308146
Phytane	42	0.99193231	0.80810609	1.15340886	0.97050265	0.78493139	1.04098952
Phytane	75	0.76941601	0.75603643	0.93771315	0.89458924	0.70300252	0.83429939
Phytane	97	1.08378562	1.20258318	1.29524567	1.37993248	1.17709214	1.37972183
Phytane	137	1.05835187	0.73732285	1.21492113	1.00797194	0.85536786	1.31026313
Phytane	158	0.9302379	0.85360273	0.92341985	1.07687114	0.84892398	1.12201771
Phytane	181	0.63577062	0.66489017	0.86405254	0.84045667	0.50539369	0.47113683

Compound	Day	G2	H2	I2	J2	A3	B3
Hexadecane	0	1	1	1	1	1	1
Hexadecane	21	0.36686707	1.20861652	0.37535545	#VALUE!	0.90880858	#DIV/0!
Hexadecane	42	0.66697542	0.72493995	0.70958323	0.74705083	0.65584155	0.84400879
Hexadecane	75	0.26743146	0.27568168	0.43127232	0.48697231	0.8410481	0.67032961
Hexadecane	97	0.74900388	0.54088516	0.50363878	0.52385787	0.70224021	0.40794582
Hexadecane	137	0.59625575	0.28208544	0.15938248	0.18607273	0.53813468	0.60523464
Hexadecane	158	0.7297847	0.27468114	0.11526837	0.72012011	0.0956044	0.52849515
Hexadecane	181	0.19265507	0.38556508	0.12446064	0.1297934	0.3638025	0.44319545
Heptadecane	0	1	1	1	1	1	1
Heptadecane	21	0.37213154	1.09265843	0.39452055	#VALUE!	0.99059019	#DIV/0!
Heptadecane	42	0.65328829	0.66268071	0.67476263	0.72855948	0.64983401	0.85998405
Heptadecane	75	0.25871818	0.29320474	0.43758575	0.45268831	0.8071233	0.65954328
Heptadecane	97	0.74688863	0.48398854	0.57878145	0.54439214	0.6703202	0.37060178
Heptadecane	137	0.55286875	0.13612583	0.10514038	0.16808445	0.48330025	0.54687299
Heptadecane	158	0.68599729	0.23118871	0.14205049	0.62314322	0.0798514	0.31400485
Heptadecane	181	0.15330324	0.31544506	0.13381722	0.13609804	0.34726603	0.42034372
Pristane	0	1	1	1	1	1	1
Pristane	21	0.39241164	1.2558987	0.37183099	#VALUE!	1.05741107	#DIV/0!
Pristane	42	0.7667171	0.90657494	0.86346918	0.84225352	0.91119583	0.92096895
Pristane	75	0.65861827	0.76800311	0.87575143	0.76898734	0.91230044	0.79251467
Pristane	97	1.16233322	1.34779691	1.21721964	1.12131148	1.38849096	0.6993306
Pristane	137	1.15146782	0.92587342	0.79796402	0.53813915	0.80186747	0.83596211
Pristane	158	1.19659467	1.13239353	0.93605998	1.02422535	0.85326923	0.97448289
Pristane	181	0.64354748	0.69620253	0.52533109	0.38450075	0.60552905	0.65971981
Octadecane	0	1	1	1	1	1	1
Octadecane	21	0.34532225	1.17557159	0.36213018	#VALUE!	0.93854201	#DIV/0!
Octadecane	42	0.69506453	0.77542159	0.71922786	0.76262046	0.71188404	0.8575895
Octadecane	75	0.30108264	0.31408518	0.41639391	0.48477057	0.84021738	0.68979517
Octadecane	97	0.81105029	0.53743552	0.59092372	0.59547023	0.64139835	0.37643967
Octadecane	137	0.63421452	0.23927636	0.13445427	0.19705409	0.51069843	0.55463875
Octadecane	158	0.74026109	0.27056163	0.11379322	0.72867309	0.08302487	0.60557151
Octadecane	181	0.14890699	0.32351784	0.10584651	0.13153973	0.33189	0.39715574
Phytane	0	1	1	1	1	1	1
Phytane	21	0.33345602	1.06029369	0.37241379	#VALUE!	1.0986089	#DIV/0!
Phytane	42	0.77947819	0.85894031	0.85741669	0.88682093	0.99566405	1.13712758
Phytane	75	0.73289853	0.74770358	1.02563626	0.83589512	0.97408252	0.99751262
Phytane	97	1.32608564	1.32407407	1.54523157	1.21850117	1.41430197	0.72862021
Phytane	137	1.35800077	0.83331317	0.87408672	0.56253742	0.81473165	0.79933232
Phytane	158	1.13975956	1.18589189	1.14424119	1.19569416	0.92562438	0.98804581
Phytane	181	0.58051441	0.60756564	0.61682964	0.43256334	0.62030164	0.67983718

Compound	Day	C3	D3	E3	F3	G3	H3
Hexadecane	0	1	1	1	1	1	1
Hexadecane	21	0.76691729	1.11142857	1.11468382	1.14246327	#DIV/0!	1.00580823
Hexadecane	42	0.75251403	0.50987571	0.68940332	0.73352157	0.69357061	0.52092338
Hexadecane	75	0.75426532	0.38654639	0.80628257	0.5599923	0.32667468	0.3435808
Hexadecane	97	0.54644403	0.92012053	0.4080859	0.40826857	0.43270374	0.9418655
Hexadecane	137	0.639906	0.66461354	0.53204401	0.44896684	0.65586164	0.38911174
Hexadecane	158	0.46595789	0.33002771	0.76141704	0.77309007	0.51652808	0.65147499
Hexadecane	181	0.14252985	0.26271836	0.14236196	0.21819744	0.12928429	0.24306178
Heptadecane	0	1	1	1	1	1	1
Heptadecane	21	0.77644231	1.08358232	1.31106988	1.15295264	#DIV/0!	1.08777867
Heptadecane	42	0.76479748	0.49908013	0.77788456	0.72204822	0.64358354	0.56384099
Heptadecane	75	0.77713494	0.40700882	0.9905837	0.60002477	0.33876698	0.4027816
Heptadecane	97	0.49723577	0.85879448	0.44291113	0.38242465	0.31362832	1.01110727
Heptadecane	137	0.56229588	0.46319726	0.57095565	0.416713	0.50905806	0.02681436
Heptadecane	158	0.21460834	0.31957804	0.03161341	0.12461841	0.42017191	0.65001793
Heptadecane	181	0.14913307	0.25652134	0.16428412	0.17177463	0.11577578	0.23119492
Pristane	0	1	1	1	1	1	1
Pristane	21	0.95700355	1.17286432	1.18657299	1.30941341	#DIV/0!	0.92582478
Pristane	42	0.75637356	0.67475898	0.8019942	0.94882279	0.74872342	0.66723268
Pristane	75	0.9685443	0.67055652	0.96906692	0.92467267	0.84037889	0.81381465
Pristane	97	0.7136863	1.3987493	0.60623624	0.7821573	0.79083408	1.24380848
Pristane	137	0.76838558	0.91306452	0.75650342	0.88837068	0.91139165	0.8917481
Pristane	158	0.64785766	0.70885015	0.81923541	1.10129388	1.11489767	0.98380118
Pristane	181	0.4619952	0.45686286	0.40689496	0.61002744	0.52622098	0.60012746
Octadecane	0	1	1	1	1	1	1
Octadecane	21	0.7345679	1.02118437	1.07264087	1.09852624	#DIV/0!	1.05195455
Octadecane	42	0.72620999	0.52950301	0.70230915	0.82309718	0.6335204	0.50867626
Octadecane	75	0.7522829	0.41127814	0.81491985	0.58280591	0.31175029	0.35790689
Octadecane	97	0.46012697	0.87922127	0.3749089	0.38192387	0.36065129	0.85799438
Octadecane	137	0.58175806	0.67242869	0.50764247	0.45317826	0.53008852	0.24330743
Octadecane	158	0.4374656	0.32730099	0.54199365	0.81353112	0.46776201	0.64708512
Octadecane	181	0.1404183	0.27175776	0.13662461	0.24110942	0.098379	0.20340711
Phytane	0	1	1	1	1	1	1
Phytane	21	0.85618932	1.06611853	1.05376344	1.11946806	#DIV/0!	1.14260326
Phytane	42	0.74118481	0.69238476	0.81458315	0.91081659	0.69446514	0.78403933
Phytane	75	0.96444298	0.72145859	0.8283623	0.9015852	0.77414356	0.98571478
Phytane	97	0.61363293	1.37440448	0.542777	0.68939394	0.6798174	1.3518833
Phytane	137	0.6944861	0.95681144	0.69014864	0.78682735	0.81881334	0.82943141
Phytane	158	0.63890607	0.75022607	0.75983157	1.05383851	1.06999908	1.27557693
Phytane	181	0.43668479	0.51110376	0.41331589	0.59723574	0.49419401	0.64766369

Compound	Day	I3	J3	A4	B4	C4	D4
Hexadecane	0	1	1	1	1	1	1
Hexadecane	21	not enuf	1.01028098	#VALUE!	0.9329393	0.63507066	1.15571441
Hexadecane	42	0.42451733	0.70221286	0.90941618	0.75426983	0.7859332	0.7759462
Hexadecane	75	0.31427652	0.42212411	#DIV/0!	0.80387993	0.68322981	0.73698774
Hexadecane	97	0.21712018	0.67781359	0.83292386	0.23878493	1.14573832	0.43154675
Hexadecane	137	0.12070142	0.44795015	0.41244057	0.36790017	0.2476468	0.26690986
Hexadecane	158	0.15266567	0.59364413	#DIV/0!	0.18625089	0.45220092	0.38999285
Hexadecane	181	0.07051301	0.46961533	0.18887518	0.44963098	0.38515482	0.4085872
Heptadecane	0	1	1	1	1	1	1
Heptadecane	21	not enuf	1.01158828	#VALUE!	0.98204137	0.67829836	1.16844956
Heptadecane	42	0.43243068	0.68307692	0.90168391	0.72924666	0.75865013	0.76589074
Heptadecane	75	0.35182523	0.47331403	#DIV/0!	0.80498264	0.69858455	0.7954641
Heptadecane	97	0.24045553	0.69934641	0.72647663	0.21456037	1.07973282	0.40745555
Heptadecane	137	0.08312905	0.42358604	0.33923929	0.36015491	0.22137214	0.25856893
Heptadecane	158	0.12305994	0.57168459	#DIV/0!	0.17859674	0.44508567	0.3887703
Heptadecane	181	0.07418204	0.3896679	0.15173379	0.36617675	0.35014621	0.39242008
Pristane	0	1	1	1	1	1	1
Pristane	21	not enuf	1.12093168	#VALUE!	1.15554533	0.72593168	1.19807063
Pristane	42	0.68021424	0.81568709	1.2403767	0.7869874	0.83239672	0.83904011
Pristane	75	0.63982365	0.79003107	#DIV/0!	0.83544853	0.94827586	1.00684814
Pristane	97	0.61606515	0.95752742	1.86297516	0.66203944	1.73090738	0.63407852
Pristane	137	0.58937881	0.7761121	1.30086293	0.78789199	0.76864113	0.77785774
Pristane	158	0.87425538	0.79032258	#DIV/0!	0.68177905	0.95372403	0.77408314
Pristane	181	0.32135007	0.80905623	0.76119665	0.62061039	0.69002952	0.64203972
Octadecane	0	1	1	1	1	1	1
Octadecane	21	not enuf	1.08258319	#VALUE!	0.97778454	0.6308096	1.11234804
Octadecane	42	0.05383372	0.78625449	0.98989316	0.80397022	0.810368	0.79963851
Octadecane	75	0.36111537	0.48427996	#DIV/0!	0.88572991	0.7044335	0.77079909
Octadecane	97	0.23320316	0.79017775	0.78019572	0.25480439	1.02022546	0.40282336
Octadecane	137	0.11770747	0.44967779	0.41886016	0.41474654	0.25759865	0.28271574
Octadecane	158	0.15078091	0.65860215	#DIV/0!	0.20834915	0.47661169	0.41438241
Octadecane	181	0.07081887	0.51438425	0.16805767	0.47424422	0.42401814	0.43493846
Phytane	0	1	1	1	1	1	1
Phytane	21	not enuf	1.05068795	#VALUE!	1.05493405	0.65993789	1.05440633
Phytane	42	0.84303605	0.80800597	1.54461478	0.80346202	0.97926267	0.90335556
Phytane	75	0.78817535	0.82903061	#DIV/0!	0.95737213	1.07142857	0.97944
Phytane	97	0.66438776	0.97944032	1.84154259	0.6558087	1.68768731	0.56938194
Phytane	137	0.67112204	0.74781816	1.39942031	0.77654867	0.78240059	0.78107834
Phytane	158	1.05339312	0.8497886	#DIV/0!	0.74211348	1.1011535	0.74554407
Phytane	181	0.40020899	0.65302905	0.82683062	0.63049622	0.79094293	0.67473325

Compound	Day	E4	F4	G4	H4	I4	J4
Hexadecane	0	1	1	1	1	1	1
Hexadecane	21	1.15605338	1.03575236	1.24841707	1.20932006	#VALUE!	1.12055788
Hexadecane	42	0.63405826	0.65431278	0.67900224	0.6070814	0.50330725	0.52850125
Hexadecane	75	0.58973497	0.61576957	0.48286819	0.39702316	0.36745573	0.33787886
Hexadecane	97	0.4747021	0.51791564	0.52329775	0.59845221	0.78323298	0.2279817
Hexadecane	137	0.63914354	0.22070201	0.41938945	0.27149992	0.30625371	0.37394418
Hexadecane	158	0.37767573	0.55821257	0.30407786	0.51993266	0.50509197	0.47963004
Hexadecane	181	0.37946501	0.24453984	0.1310516	0.33876456	0.14199477	0.34510832
Heptadecane	0	1	1	1	1	1	1
Heptadecane	21	1.18187307	1.12267652	1.31435488	1.1970516	#VALUE!	1.14125
Heptadecane	42	0.71716435	0.69642472	0.71490423	0.64151717	0.5147722	0.53488159
Heptadecane	75	0.63900591	0.65044248	0.55897841	0.42728111	0.42588378	0.38380676
Heptadecane	97	0.45150937	0.4884189	0.52028456	0.55619048	0.77341197	0.22273182
Heptadecane	137	0.6142664	0.22362804	0.40225531	0.2789511	0.29060055	0.33018172
Heptadecane	158	0.36661749	0.54860688	0.31352641	0.51465798	0.47710972	0.4471479
Heptadecane	181	0.37094334	0.24910263	0.14286441	0.33685551	0.1601064	0.35445161
Pristane	0	1	1	1	1	1	1
Pristane	21	1.30878811	1.21389895	1.10847821	1.18673219	#VALUE!	1.18869803
Pristane	42	0.88621328	0.78501892	0.75104293	0.72501281	0.74342002	0.71956585
Pristane	75	0.98799469	0.89606941	0.76353857	0.80199693	0.93483775	0.80878556
Pristane	97	0.76876702	0.60492325	0.63500762	0.69365079	1.59952607	0.42224494
Pristane	137	0.82107051	0.52659041	0.65785259	0.87751004	0.89052226	0.73668035
Pristane	158	0.91020187	0.89296457	0.66620814	0.78872602	1.16264869	0.94506507
Pristane	181	0.66066876	0.49564547	0.35054088	0.65637598	0.54676208	0.67611838
Octadecane	0	1	1	1	1	1	1
Octadecane	21	1.09879514	1.11960251	1.16652713	1.13317872	#VALUE!	1.10049107
Octadecane	42	0.68413705	0.67645864	0.70183897	0.62588752	0.53189555	0.57567478
Octadecane	75	0.61966945	0.6276285	0.52296488	0.43363108	0.39163353	0.36286312
Octadecane	97	0.42681964	0.49277978	0.52001258	0.56747664	0.6607566	0.23209451
Octadecane	137	0.58924413	0.23415864	0.40392107	0.2928605	0.28144545	0.34305778
Octadecane	158	0.40918082	0.62075344	0.31589396	0.57470243	0.4937408	0.50761278
Octadecane	181	0.35223827	0.263071	0.13990277	0.32805345	0.15548173	0.33422888
Phytane	0	1	1	1	1	1	1
Phytane	21	1.15124018	1.19381645	1.01858124	1.17285581	#VALUE!	1.05658754
Phytane	42	0.77623581	0.83066969	0.87506257	0.764218	0.72519465	0.7168588
Phytane	75	0.99880377	0.83679039	0.86037652	0.87357528	0.94607748	0.78941317
Phytane	97	0.67547528	0.65990888	0.69946253	0.76237926	1.53944817	0.42353414
Phytane	137	0.7084913	0.57196709	0.68512625	1.00865846	0.86453578	0.69182809
Phytane	158	0.92022313	1.09463827	0.76221217	0.87342785	1.21961476	1.056536
Phytane	181	0.60546903	0.5254212	0.37706509	0.70898922	0.53537332	0.69283194

		Plot					
Compound	Day	A2	B2	C2	D2	E2	F2
n-eicosane	0	1	1	1	1	1	1
n-eicosane	21	1.03686735	1.26300475	#DIV/0!	1.17994687	1.0717832	1.17114569
n-eicosane	42	0.8894182	0.88200924	0.79212271	0.85273117	0.74100266	0.91394777
n-eicosane	75	0.56916626	0.6577431	0.59542011	0.72202812	0.33800121	0.5677613
n-eicosane	97	0.24294467	0.87012813	0.56843797	0.95044755	0.38390355	0.95976817
n-eicosane	137	0.26978938	0.70153078	0.35210723	0.84096459	0.82988547	0.59468283
n-eicosane	158	0.20303745	0.66107961	0.19187827	0.90181932	0.44964463	0.83032622
n-eicosane	181	0.41339156	0.55551604	0.16476778	0.37743839	0.23541577	0.27303788
Docosane	0	1	1	1	1	1	1
Docosane	21	1.03969423	1.29498612	#DIV/0!	1.21916476	1.0542916	1.19072039
Docosane	42	0.84610146	0.87746336	0.7488276	0.8168267	0.70284304	0.91034245
Docosane	75	0.48182156	0.61038788	0.53608925	0.65304365	0.2612337	0.51769347
Docosane	97	0.02679021	0.93773029	0.43256084	0.85513431	0.27300773	0.89756098
Docosane	137	0.14875225	0.68343521	0.23997322	0.82857143	0.79956114	0.47296752
Docosane	158	0.08471711	0.60300999	0.11778621	0.86787837	0.34605635	0.7199101
Docosane	181	0.38612693	0.54319082	0.10300737	0.29698442	0.20824825	0.25550604
n-tetracosane	0	1	1	1	1	1	1
n-tetracosane	21	1.03460838	1.33985809	#DIV/0!	1.2905136	1.0714361	1.23605442
n-tetracosane	42	0.8025493	0.85136816	0.70269258	0.79585905	0.70255404	0.89309684
n-tetracosane	75	0.45676443	0.64032294	0.47843588	0.60881768	0.23904328	0.51292825
n-tetracosane	97	0.05046198	0.85244448	0.44228971	0.89821824	0.28225398	0.8815331
n-tetracosane	137	0.14476454	0.64095967	0.24407229	0.80915179	0.78726833	0.36205468
n-tetracosane	158	0.0897598	0.70327111	0.15255148	0.98713188	0.38926096	0.77757541
n-tetracosane	181	0.38080742	0.5754222	0.11962743	0.30868625	0.188637	0.24622166
Hexacosane	0	1	1	1	1	1	1
Hexacosane	21	1.01844262	1.27749047	#DIV/0!	1.20339918	1.04226747	1.14145915
Hexacosane	42	0.8486532	0.92239199	0.68720049	0.76659405	0.77021163	0.90068346
Hexacosane	75	0.47490066	0.62255878	0.1198642	0.65398723	0.28007696	0.51367844
Hexacosane	97	0.14570896	0.76747893	0.38593517	0.77104874	0.28886372	0.78227791
Hexacosane	137	0.1961326	0.72737981	0.25556845	0.83078686	0.82854534	0.4587308
Hexacosane	158	0.11519174	0.58550023	0.14292247	0.79765795	0.31165514	0.66715889
Hexacosane	181	0.31879756	0.52391295	0.10347735	0.2423658	0.19993454	0.22748596
n-octacosane	0	1	1	1	1	1	1
n-octacosane	21	1.13114754	1.26455303	#DIV/0!	1.28174135	1.08473732	1.1592674
n-octacosane	42	0.86868687	0.93102322	0.66101794	0.73886158	0.80166955	0.92142488
n-octacosane	75	0.45298013	0.58392829	0.44645776	0.65631153	0.2605426	0.50595197
n-octacosane	97	0.02238806	0.79640729	0.34260209	0.7755977	0.24256201	0.86994371
n-octacosane	137	0.17403315	0.6667823	0.22818952	0.84323641	0.86873299	0.431534
n-octacosane	158	0.08849558	0.62764464	0.13569523	0.87565552	0.31221973	0.72630095
n-octacosane	181	0.40182648	0.60982702	0.0879032	0.277673	0.25163331	0.28521604

Compound	Day	G2	H2	I2	J2	A3	B3
n-eicosane	0	1	1	1	1	1	1
n-eicosane	21	0.36859967	1.17014287	0.36923077	#VALUE!	0.90266798	#DIV/0!
n-eicosane	42	0.71372864	0.76645181	0.70420026	0.76026371	0.69059741	0.86852086
n-eicosane	75	0.32199035	0.32388653	0.4510934	0.50811339	0.80793042	0.69390899
n-eicosane	97	0.85213779	0.59321899	0.63196009	0.62392745	0.65510909	0.37964368
n-eicosane	137	0.65231478	0.27046106	0.12041127	0.20552514	0.49993882	0.58700031
n-eicosane	158	0.77063717	0.27927825	0.12690175	0.75047048	0.14116587	0.56048166
n-eicosane	181	0.19779391	0.32042349	0.13174512	0.1472556	0.33424355	0.41754073
Docosane	0	1	1	1	1	1	1
Docosane	21	0.37169231	1.18421875	0.37	#VALUE!	0.90266798	#DIV/0!
Docosane	42	0.68443087	0.71608498	0.67625941	0.7234268	0.63277488	0.84808448
Docosane	75	0.24368876	0.24185017	0.29763097	0.41571827	0.78524129	0.65529674
Docosane	97	0.72632911	0.44765217	0.50146444	0.51219732	0.55963143	0.35449998
Docosane	137	0.53046238	0.17563589	0.0795297	0.1448357	0.48642696	0.55534516
Docosane	158	0.67448154	0.20937695	0.08955638	0.58674247	0.07319712	0.58553466
Docosane	181	0.12777487	0.2756962	0.07929104	0.10758966	0.30889527	0.38567725
n-tetracosane	0	1	1	1	1	1	1
n-tetracosane	21	0.36899703	1.16373698	0.3627907	#VALUE!	0.89706135	#DIV/0!
n-tetracosane	42	0.64249598	0.63290339	0.70256258	0.68017335	0.58287389	0.83398612
n-tetracosane	75	0.24282325	0.25023647	0.29742538	0.39514362	0.75212974	0.602821
n-tetracosane	97	0.72865235	0.41449275	0.47640362	0.52055485	0.51557114	0.32369016
n-tetracosane	137	0.4199802	0.19722706	0.09335713	0.17190019	0.48535883	0.56821748
n-tetracosane	158	0.61614043	0.23511596	0.10523148	0.62799567	0.07274247	0.69208173
n-tetracosane	181	0.14410212	0.2862166	0.09736203	0.11091368	0.35103134	0.38959087
Hexacosane	0	1	1	1	1	1	1
Hexacosane	21	0.36505495	1.08878443	0.36923077	#VALUE!	0.86787126	#DIV/0!
Hexacosane	42	0.68208894	0.58233242	0.73827446	0.77348089	0.59848659	0.8739103
Hexacosane	75	0.22130918	0.25677036	0.26294892	0.39364828	0.83578685	0.67769959
Hexacosane	97	0.6444123	0.38639155	0.47602189	0.5317096	0.57043513	0.29961403
Hexacosane	137	0.53589212	0.14602896	0.09904798	0.14365944	0.43924269	0.47422818
Hexacosane	158	0.54549905	0.22022458	0.13777904	0.55026157	0.15934066	0.69116954
Hexacosane	181	0.09377972	0.25370092	0.09758898	0.10985736	0.31260067	0.35842485
n-octacosane	0	1	1	1	1	1	1
n-octacosane	21	0.35280374	1.15478516	0.38297872	#VALUE!	0.92302892	#DIV/0!
n-octacosane	42	0.6990242	0.62594841	0.77283199	0.73483568	0.62841091	0.97298381
n-octacosane	75	0.19927819	0.23020715	0.20815985	0.28122363	0.81743182	0.67180051
n-octacosane	97	0.6430853	0.3826087	0.43585863	0.50754098	0.554059	0.34826664
n-octacosane	137	0.43629901	0.17966028	0.11280809	0.14417435	0.52961319	0.55933908
n-octacosane	158	0.5336352	0.22488318	0.12034452	0.49419718	0.13208502	0.81960972
n-octacosane	181	0.12325021	0.3648369	0.09717371	0.13671138	0.369334	0.44349058

Compound	Day	C3	D3	E3	F3	G3	H3
n-eicosane	0	1	1	1	1	1	1
n-eicosane	21	0.8005137	1.02140632	1.07448107	1.12899821	#DIV/0!	1.06340795
n-eicosane	42	0.70507031	0.54667359	0.69504733	0.80653053	0.63011542	0.53889717
n-eicosane	75	0.75017878	0.44215711	0.78510108	0.59964587	0.25119219	0.3967465
n-eicosane	97	0.47757871	0.86444444	0.3856077	0.41391969	0.37323006	0.91024166
n-eicosane	137	0.61332616	0.6564933	0.5084303	0.47885549	0.5199429	0.28234509
n-eicosane	158	0.46176708	0.35586789	0.51933963	0.77891918	0.49426052	0.71900024
n-eicosane	181	0.1558066	0.26465428	0.15922923	0.25911195	0.14011901	0.24379204
Docosane	0	1	1	1	1	1	1
Docosane	21	0.79091928	1.02161616	1.07628997	1.15476426	#DIV/0!	1.06805716
Docosane	42	0.71450058	0.5064422	0.67022595	0.75627991	0.60709493	0.51046607
Docosane	75	0.71519647	0.38721099	0.74427831	0.51000549	0.21939707	0.26634034
Docosane	97	0.46936046	0.75442424	0.35236162	0.36308478	0.31493824	0.80374256
Docosane	137	0.59939804	0.65467192	0.4699109	0.39383972	0.43241157	0.16827705
Docosane	158	0.4333638	0.30158088	0.48117599	0.76064686	0.38227701	0.53446435
Docosane	181	0.1205548	0.23786524	0.11658244	0.20622557	0.08221196	0.16919321
n-tetracosane	0	1	1	1	1	1	1
n-tetracosane	21	0.80512422	1.03607748	1.11553785	1.20139258	#DIV/0!	1.04601957
n-tetracosane	42	0.78155334	0.47373509	0.74268025	0.76888427	0.56915551	0.54842537
n-tetracosane	75	0.73261606	0.34268297	0.75844442	0.51160232	0.22011074	0.26500609
n-tetracosane	97	0.49963788	0.79851224	0.35236979	0.36034526	0.29588126	0.79988341
n-tetracosane	137	0.60969438	0.68789618	0.52486134	0.42990697	0.44088741	0.27198331
n-tetracosane	158	0.42874946	0.29702494	0.56805412	0.72385497	0.38066595	0.54132601
n-tetracosane	181	0.11560128	0.23998312	0.12828561	0.22672597	0.10965789	0.18853628
Hexacosane	0	1	1	1	1	1	1
Hexacosane	21	0.7900641	1.1009434	1.04417671	1.09914641	#DIV/0!	1.0118085
Hexacosane	42	0.75905945	0.53280224	0.71994349	0.75269723	0.57992283	0.49424011
Hexacosane	75	0.73348979	0.42725454	0.71475852	0.51473139	0.21458466	0.21951615
Hexacosane	97	0.41411428	0.84813417	0.30321957	0.26458918	0.25102242	0.74144954
Hexacosane	137	0.51543789	0.63028862	0.40209859	0.30135636	0.33280627	0.15841848
Hexacosane	158	0.51034011	0.41229248	0.62394099	0.84487804	0.41358385	0.55414437
Hexacosane	181	0.145819	0.23902986	0.12123377	0.1947713	0.09259289	0.14480089
n-octacosane	0	1	1	1	1	1	1
n-octacosane	21	0.84543011	1.19508449	1.08987969	1.17152594	#DIV/0!	0.92273869
n-octacosane	42	0.86625749	0.55770609	0.72075092	0.78162091	0.5831126	0.46311475
n-octacosane	75	0.72473847	0.4043659	0.72469294	0.46096086	0.17841475	0.1707271
n-octacosane	97	0.49092579	0.80867384	0.35266174	0.28872714	0.27028676	0.71518987
n-octacosane	137	0.56704646	0.74524931	0.43969339	0.31735032	0.36535133	0.13632311
n-octacosane	158	0.55420862	0.41176576	0.72780722	0.91198755	0.34852766	0.52360989
n-octacosane	181	0.16677246	0.29648169	0.13245625	0.22665389	0.09799454	0.11568171

Compound	Day	I3	J3	A4	B4	C4	D4
n-eicosane	0	1	1	1	1	1	1
n-eicosane	21	not enuf	1.01259283	#VALUE!	0.9606469	0.64651113	1.11873351
n-eicosane	42	0.48560462	0.75285425	0.99293174	0.78838305	0.80886804	0.80972222
n-eicosane	75	0.37150914	0.47535004	#DIV/0!	0.8425569	0.74273375	0.75694872
n-eicosane	97	0.26646568	0.76799536	0.83333757	0.26589666	1.00607806	0.4140625
n-eicosane	137	0.00713487	0.48380201	0.48770564	0.41326531	0.29602074	0.32565284
n-eicosane	158	0.14312407	0.64083722	#DIV/0!	0.23959664	0.48934204	0.45106383
n-eicosane	181	0.09277572	0.44893669	0.18634529	0.47497382	0.42305073	0.44328055
Docosane	0	1	1	1	1	1	1
Docosane	21	not enuf	0.99864823	#VALUE!	0.96226415	0.6452726	1.14149844
Docosane	42	0.4317781	0.71295958	0.90292752	0.76483516	0.78816541	0.78844592
Docosane	75	0.29722425	0.37934686	#DIV/0!	0.79932203	0.67416226	0.71664452
Docosane	97	0.20115546	0.68394816	0.68813481	0.19787234	0.99825894	0.38150609
Docosane	137	0.07181506	0.39705073	0.35082242	0.35714286	0.22610411	0.25316533
Docosane	158	0.11113163	0.58436987	#DIV/0!	0.16470588	0.42731386	0.3965808
Docosane	181	0.05414592	0.37051098	0.14635578	0.47120419	0.40673345	0.43215672
n-tetracosane	0	1	1	1	1	1	1
n-tetracosane	21	not enuf	1.02457618	#VALUE!	0.97110849	0.66084815	1.16987931
n-tetracosane	42	0.37839321	0.67979973	0.88060797	0.76957418	0.7626993	0.78416281
n-tetracosane	75	0.31548168	0.35699789	#DIV/0!	0.75222458	0.63669951	0.7312037
n-tetracosane	97	0.17764378	0.63104769	0.61306556	0.18849734	1.08974359	0.37103749
n-tetracosane	137	0.0879247	0.41450025	0.36595593	0.3515625	0.21605048	0.27929254
n-tetracosane	158	0.12301573	0.54948463	#DIV/0!	0.13897059	0.4025166	0.3845876
n-tetracosane	181	0.067804	0.38387738	0.17817226	0.52126963	0.45601951	0.45457775
Hexacosane	0	1	1	1	1	1	1
Hexacosane	21	not enuf	1.011476	#VALUE!	0.87331536	0.57676763	1.08736715
Hexacosane	42	0.40231092	0.66515837	0.83775717	0.70845481	0.79190602	0.76018951
Hexacosane	75	0.29274858	0.3692083	#DIV/0!	0.83773781	0.67270059	0.74794393
Hexacosane	97	0.165748	0.59342561	0.6489037	0.1670647	0.83596769	0.32699328
Hexacosane	137	0.09031844	0.33357401	0.2938094	0.3148688	0.18155981	0.20771782
Hexacosane	158	0.05111574	0.6601518	#DIV/0!	0.1879952	0.49323577	0.45668456
Hexacosane	181	0.0678926	0.32929021	0.17213252	0.41110161	0.38933172	0.38431591
n-octacosane	0	1	1	1	1	1	1
n-octacosane	21	not enuf	1.12073381	#VALUE!	0.99205561	0.60295964	1.16461906
n-octacosane	42	0.33778764	0.65870052	0.85220126	0.73395026	0.79660967	0.79994575
n-octacosane	75	0.26101772	0.31649602	#DIV/0!	0.83336307	0.57962529	0.73703125
n-octacosane	97	0.19265594	0.6156482	0.53620894	0.19652856	1.03019476	0.40651449
n-octacosane	137	0.07860643	0.38862991	0.29716723	0.33834586	0.15801927	0.1984447
n-octacosane	158	0.12901324	0.70975572	#DIV/0!	0.2006192	0.46650036	0.46356541
n-octacosane	181	0.06764096	0.39603052	0.1985348	0.51336456	0.45641297	0.4655051

Compound	Day	E4	F4	G4	H4	I4	J4
n-eicosane	0	1	1	1	1	1	1
n-eicosane	21	1.13651505	1.16885309	1.19967735	1.14354584	#VALUE!	1.16650905
n-eicosane	42	0.66464025	0.67785786	0.69833474	0.61202622	0.53491034	0.58524599
n-eicosane	75	0.62709777	0.64318182	0.51303136	0.44556294	0.43661831	0.39917933
n-eicosane	97	0.42461813	0.48126026	0.50184255	0.57275188	0.75767024	0.24707547
n-eicosane	137	0.61647373	0.23797447	0.39937573	0.33603044	0.34408293	0.37153257
n-eicosane	158	0.41407359	0.61210872	0.35617471	0.57158923	0.55377103	0.52186805
n-eicosane	181	0.39961126	0.29245296	0.16809899	0.36727261	0.19205455	0.38170231
Docosane	0	1	1	1	1	1	1
Docosane	21	1.15643024	1.18704141	1.26688833	1.15702961	#VALUE!	1.18307592
Docosane	42	0.65657958	0.65744795	0.68842873	0.55709354	0.49299381	0.5393481
Docosane	75	0.55826658	0.59470339	0.47612132	0.33597079	0.30697195	0.28819912
Docosane	97	0.38850009	0.48331396	0.48383675	0.55618021	0.6292913	0.20665082
Docosane	137	0.59769245	0.20294011	0.33932073	0.24200305	0.20740951	0.26976587
Docosane	158	0.34638994	0.58769177	0.30335901	0.53069001	0.40702706	0.41981262
Docosane	181	0.37511677	0.28438596	0.15285348	0.35373627	0.15521569	0.37868793
n-tetracosane	0	1	1	1	1	1	1
n-tetracosane	21	1.19618994	1.23158984	1.28314457	1.19443824	#VALUE!	1.22307547
n-tetracosane	42	0.7029548	0.67625344	0.66069775	0.56104096	0.53548551	0.53965938
n-tetracosane	75	0.52899575	0.54893868	0.45929635	0.34206116	0.30633073	0.30864439
n-tetracosane	97	0.3636506	0.48968054	0.4764328	0.57251082	0.0735266	0.19558375
n-tetracosane	137	0.59577677	0.24494869	0.36307424	0.23117067	0.22470241	0.30968836
n-tetracosane	158	0.35682887	0.5522661	0.27088608	0.49718685	0.3804872	0.38450844
n-tetracosane	181	0.4150355	0.29939777	0.17260762	0.35735779	0.17621905	0.39504635
Hexacosane	0	1	1	1	1	1	1
Hexacosane	21	1.09482437	1.18881857	1.17225553	1.09368015	#VALUE!	1.17531716
Hexacosane	42	0.66764657	0.6743393	0.64307914	0.524913	0.49829813	0.53663321
Hexacosane	75	0.58607363	0.62049279	0.46588125	0.31653789	0.28511924	0.29674126
Hexacosane	97	0.32203631	0.4232852	0.39929606	0.46444683	0.46934039	0.18446849
Hexacosane	137	0.52232484	0.20195366	0.28564134	0.27355419	0.17580702	0.24358544
Hexacosane	158	0.40349099	0.61340206	0.33589873	0.54752516	0.39464765	0.46229379
Hexacosane	181	0.31074171	0.26800607	0.15103166	0.31108006	0.13934374	0.31960161
n-octacosane	0	1	1	1	1	1	1
n-octacosane	21	1.17325571	1.2577162	1.22988506	1.16789517	#VALUE!	1.3444863
n-octacosane	42	0.72885996	0.73302858	0.64793944	0.54490575	0.50040733	0.57553643
n-octacosane	75	0.5430519	0.57874016	0.438588	0.26693975	0.23126338	0.28495146
n-octacosane	97	0.36725746	0.53804827	0.49689828	0.57601411	0.40947867	0.25122929
n-octacosane	137	0.59122886	0.24481356	0.28687552	0.24269628	0.14635163	0.25230876
n-octacosane	158	0.40311058	0.64414319	0.32468966	0.57160092	0.27835052	0.48774333
n-octacosane	181	0.3484739	0.31290706	0.17985416	0.35462197	0.13562791	0.40849334

		Plot					
Compound	Day	A2	B2	C2	D2	E2	F2
Tricontane	0	1	1	1	1	1	1
Tricontane	21	1.09267313	1.13548985	#DIV/0!	1.18291579	0.96157289	1.1047619
Tricontane	42	0.95135024	0.96315314	0.6435997	0.66718954	0.8771208	1.00671141
Tricontane	75	0.47211785	0.57731157	0.43738909	0.65871485	0.2970893	0.58371041
Tricontane	97	0.16219921	0.82479654	0.33286908	0.7650013	0.28765001	0.87804878
Tricontane	137	0.20413801	0.65846251	0.22277276	0.8407563	0.96629124	0.47058824
Tricontane	158	0.15387394	0.76644969	0.18128034	1.00194263	0.42503863	0.94342629
Tricontane	181	0.47637685	0.67629489	0.10568986	0.28711025	0.31425698	0.34256927
n-dotriacontane	0	1	1	1	1	1	1
n-dotriacontane	21	1.13160291	1.08374839	#DIV/0!	1.15899818	0.86817063	1.08235294
n-dotriacontane	42	0.91638608	0.98481751	0.64533277	0.65012738	0.8440219	0.98065535
n-dotriacontane	75	0.45452539	0.64001005	0.42859945	0.6626587	0.29041614	0.59382486
n-dotriacontane	97	0.17661692	0.87145439	0.30834189	0.77784812	0.22846596	0.87116212
n-dotriacontane	137	0.21247698	0.56810609	0.20537057	0.80555556	0.91552238	0.49320142
n-dotriacontane	158	0.06981318	0.84282142	0.19540112	0.99238193	0.43088006	1.01767049
n-dotriacontane	181	0.54033486	0.83570139	0.11075803	0.38737098	0.3593718	0.43621277
Hexatricontane	0	1	1	1	1	1	1
Hexatricontane	21	0.09059929	0.87438791	#DIV/0!	0.99468858	0.77988209	0.94358974
Hexatricontane	42	0.06074944	0.9256028	0.40425806	0.68781082	0.86417259	0.94992256
Hexatricontane	75	0.04004439	0.72908905	0.63814788	0.77476716	0.45654401	0.73117531
Hexatricontane	97	0.02183451	0.94402942	0.56190744	1.02203175	0.61569639	1.08167605
Hexatricontane	137	0.05118845	0.43053757	0.50944076	0.71478873	0.69391553	0.72704098
Hexatricontane	158	0.0517845	0.85486173	0.46833526	1.02616936	0.64107102	1.06764736
Hexatricontane	181	0.0653152	0.86513629	0.42749986	0.540137	0.58266069	0.60014209
n-hexatriaconta	0	1	1	1	1	1	1
n-hexatriaconta	21	0.03578191	0.70133197	#DIV/0!	0.79799875	0.71227621	0.73015873
n-hexatriaconta	42	0.04409488	0.96794495	0.75472156	0.67513228	0.96200345	0.97762864
n-hexatriaconta	75	0.03221388	0.80987785	0.59121831	0.93551816	0.39611907	0.67647059
n-hexatriaconta	97	0	0.81127528	0.36312991	0.80776535	0.6300905	0.74796748
n-hexatriaconta	137	0.02842501	0.42643286	0.40930498	0.64115646	0.80276503	0.77492405
n-hexatriaconta	158	0	0.87139923	0.42188879	0.99628895	0.62968685	1.05073041
n-hexatriaconta	181	0.02562853	0.87783972	0.34162379	0.58105647	0.51920718	0.58900084

Compound	Day	G2	H2	I2	J2	A3	B3
Tricontane	0	1	1	1	1	1	1
Tricontane	21	0.3016983	0.96547068	0.30857143	#VALUE!	0.74703557	#DIV/0!
Tricontane	42	0.75181477	0.61615991	0.80999256	0.79709223	0.63563403	1.06759907
Tricontane	75	0.23170777	0.24547722	0.21890821	0.29629441	0.66618287	0.69037192
Tricontane	97	0.59575867	0.35308642	0.40239091	0.54574299	0.61335188	0.44154658
Tricontane	137	0.42386341	0.18453994	0.13417256	0.21626153	0.59638554	0.74916004
Tricontane	158	0.68361181	0.31623784	0.21008714	0.67987279	0.10384615	0.91799501
Tricontane	181	0.14843381	0.38248164	0.108742	0.17984712	0.40589766	0.51324742
n-dotriacontane	0	1	1	1	1	1	1
n-dotriacontane	21	0.30039788	0.91572746	0.35	#VALUE!	0.82529644	#DIV/0!
n-dotriacontane	42	0.76844784	0.64031444	0.90807759	0.87541613	0.71219904	1.10744511
n-dotriacontane	75	0.21007652	0.23282968	0.2259245	0.29689298	0.81444122	0.73534921
n-dotriacontane	97	0.5602357	0.30577334	0.42677824	0.53830104	0.59895688	0.53073522
n-dotriacontane	137	0.46299354	0.22972954	0.14517327	0.26541187	0.71539157	0.91770736
n-dotriacontane	158	0.6922019	0.36514989	0.23567468	0.81925736	0	1.06666371
n-dotriacontane	181	0.17684753	0.48505914	0.12686567	0.27089825	0.5432784	0.65691706
Hexatricontane	0	1	1	1	1	1	1
Hexatricontane	21	0.462932	0.83789063	0.54545455	#VALUE!	0.85968379	#DIV/0!
Hexatricontane	42	0.74246168	0.69748537	1.20003158	0.74073673	1.28009631	1.22265512
Hexatricontane	75	0.36578541	0.53332252	0.73403138	0.36897517	1.1574746	0.8880363
Hexatricontane	97	0.88644285	0.74608696	0.75656143	0.61815889	1.3713491	0.8685686
Hexatricontane	137	0.70651678	0.52939895	0.60594059	0.53233606	1.18795181	1.06603448
Hexatricontane	158	0.81459123	0.6523142	0.71987901	1.03982665	0.61346154	1.35313911
Hexatricontane	181	0.4374688	0.72106691	0.55359566	0.5249914	0.95576756	0.82211238
n-hexatriaconta	0	1	1	1	1	1	1
n-hexatriaconta	21	0	0.6130907	0	#VALUE!	0.47613256	#DIV/0!
n-hexatriaconta	42	0.88978171	0.74096007	1.1074117	1.22990249	1.06346463	1.47199265
n-hexatriaconta	75	0.45806158	0.49486448	0.50833012	0.72224927	0.81589818	0.82448245
n-hexatriaconta	97	0.6035976	0.42460233	0.64016736	0.58562421	0.89354873	0.87886783
n-hexatriaconta	137	0.80452156	0.43293745	0.37871287	0.58224257	0.95546803	1.17251829
n-hexatriaconta	158	0.91564954	0.67908973	0.42421442	1.18517876	0	1.53765807
n-hexatriaconta	181	0.40874384	0.74714418	0.30923507	0.65069357	0.73133631	0.86652162

Compound	Day	C3	D3	E3	F3	G3	H3
Tricontane	0	1	1	1	1	1	1
Tricontane	21	0.71875	0.9632381	0.96866097	1.04851371	#DIV/0!	0.88424112
Tricontane	42	0.95530973	0.53019259	0.76354855	0.83299192	0.5635901	0.45711227
Tricontane	75	0.69728814	0.37201663	0.71168218	0.45156477	0.17701076	0.16276948
Tricontane	97	0.54809242	0.81257778	0.38718806	0.32700648	0.27303544	0.65912626
Tricontane	137	0.69873532	0.8117175	0.55848835	0.39606749	0.43953818	0.19966262
Tricontane	158	0.56847134	0.39808676	0.71105533	0.89407908	0.32333144	0.44690674
Tricontane	181	0.21288014	0.31795658	0.17200688	0.26895999	0.11878931	0.14371091
n-dotriacontane	0	1	1	1	1	1	1
n-dotriacontane	21	0.765	0.92619048	0.96385542	1.01918465	#DIV/0!	0.78322648
n-dotriacontane	42	1.07415929	0.54427984	0.81800888	0.85516325	0.60572568	0.46969042
n-dotriacontane	75	0.70535593	0.4043659	0.80410333	0.45849846	0.18318247	0.12878122
n-dotriacontane	97	0.6584417	0.86444444	0.51980497	0.39184397	0.31586453	0.67819729
n-dotriacontane	137	0.79364047	1.00597467	0.69203284	0.45373665	0.53453997	0.25547808
n-dotriacontane	158	0.64426752	0.42068348	0.85741568	0.96280527	0.3740501	0.51587181
n-dotriacontane	181	0.24815742	0.44160636	0.26671428	0.31852248	0.12368064	0.14958842
Hexatricontane	0	1	1	1	1	1	1
Hexatricontane	21	0.68432203	0.83357143	0.84765178	0.9352518	#DIV/0!	0.62867911
Hexatricontane	42	1.09236538	0.53307407	0.86572236	0.93773728	0.64148032	0.58375809
Hexatricontane	75	0.82357943	0.56611227	0.8649736	0.66238913	0.40210786	0.38489815
Hexatricontane	97	0.83700216	1.29666667	0.68199841	0.67173252	0.55276292	1.1238698
Hexatricontane	137	0.87611961	1.04586677	0.79859005	0.7104728	0.73121034	0.51015324
Hexatricontane	158	0.77218504	0.62741935	0.99458102	1.07418289	0.68575851	0.71595637
Hexatricontane	181	0.43813105	0.5837484	0.46335462	0.54481493	0.34928329	0.39061357
n-hexatriaconta	0	1	1	1	1	1	1
n-hexatriaconta	21	0.5	0.64430642	0.64646465	0.79100898	#DIV/0!	0.68573801
n-hexatriaconta	42	1.23362832	0.8268599	0.96373709	1.0268702	0.72095423	0.6371868
n-hexatriaconta	75	0.91050847	0.38678478	0.92454478	0.75527251	0.39221997	0.35944927
n-hexatriaconta	97	0.83127351	1.01478261	0.70598966	0.64332592	0.4401391	0.72731174
n-hexatriaconta	137	0.95212285	1.22164841	0.79523173	0.772782	0.79403904	0.54624678
n-hexatriaconta	158	0.81210191	0.67727427	1.2210214	1.19772283	0.67758256	0.83676156
n-hexatriaconta	181	0.39534884	0.5832084	0.50007091	0.55092844	0.36383285	0.40773793

Compound	Day	I3	J3	A4	B4	C4	D4
Tricontane	0	1	1	1	1	1	1
Tricontane	21	not enuf	0.98094931	#VALUE!	0.88854761	0.4697205	1.00365545
Tricontane	42	0.37791271	0.69036437	0.80396345	0.68310759	0.80701165	0.77751736
Tricontane	75	0.26927213	0.32010104	#DIV/0!	0.79818683	0.53440126	0.70114583
Tricontane	97	0.21494898	0.64473684	0.39659228	0.24047501	1.16987179	0.4423376
Tricontane	137	0.12557377	0.43093293	0.41428974	0.44850498	0.21262887	0.26459293
Tricontane	158	0.14884903	0.71233022	#DIV/0!	0.22161423	0.48253106	0.46538332
Tricontane	181	0.09204807	0.44251311	0.22187488	0.54243273	0.5117866	0.46331963
n-dotriacontane	0	1	1	1	1	1	1
n-dotriacontane	21	not enuf	1.00204499	#VALUE!	0.94860117	0.51749585	1.04264318
n-dotriacontane	42	0.4037529	0.68683761	1.01342852	0.79802956	0.7963377	0.81621732
n-dotriacontane	75	0.26399228	0.36491518	#DIV/0!	0.82372881	0.52510608	0.73264706
n-dotriacontane	97	0.2442602	0.69389978	0.48693569	0.29713866	1.47816705	0.58929483
n-dotriacontane	137	0.13080601	0.52787806	0.49974068	0.56527094	0.28631214	0.32685009
n-dotriacontane	158	0.14312407	0.79764038	#DIV/0!	0.30669371	0.5232458	0.54408785
n-dotriacontane	181	0.11116916	0.65092251	0.34671358	0.68730818	0.62022455	0.59239091
Hexatricontane	0	1	1	1	1	1	1
Hexatricontane	21	not enuf	1.17976618	#VALUE!	1.22264151	0.61131089	0.88505069
Hexatricontane	42	0.477582	0.8022061	1.48447961	1.03252747	0.71434635	0.8310307
Hexatricontane	75	0.57927449	0.69310934	#DIV/0!	1.10928814	0.68233083	0.81592105
Hexatricontane	97	0.58622449	0.38068812	1.25922616	0.62042553	2.36302294	0.81056972
Hexatricontane	137	0.52322404	0.89258225	1.19292936	1.00285714	0.45659251	0.50133398
Hexatricontane	158	0.62156737	1.13329276	#DIV/0!	0.76235294	0.86194835	0.72563057
Hexatricontane	181	0.42307807	0.96205528	1.00006363	1.05172775	0.87919551	0.71775434
n-hexatriaconta	0	1	1	1	1	1	1
n-hexatriaconta	21	not enuf	0.76823449	#VALUE!	0.67924528	0.43995859	0.6610698
n-hexatriaconta	42	0.60036301	0.80410256	1.16209262	0.89010989	0.90128435	0.89169823
n-hexatriaconta	75	0.51650664	0.66901117	#DIV/0!	1.03728814	0.68452381	0.87931818
n-hexatriaconta	97	0.38232032	0.64052288	0	0.33510638	1.93181818	0.78839173
n-hexatriaconta	137	0.46256039	0.87605295	0.99806164	0.80357143	0.58419244	0.46905111
n-hexatriaconta	158	0.39825827	1.05376344	#DIV/0!	0.74117647	0.83592133	0.84086304
n-hexatriaconta	181	0.42630957	0.9703567	0.77747893	0.96596859	0.94913151	0.76292769

Compound	Day	E4	F4	G4	H4	I4	J4
Tricontane	0	1	1	1	1	1	1
Tricontane	21	1.0664655	1.12418983	1.04926071	0.98438615	#VALUE!	0.98383621
Tricontane	42	0.75563931	0.72620209	0.61995953	0.52707462	0.49639011	0.53632133
Tricontane	75	0.53809181	0.55025773	0.40548857	0.26053218	0.23680263	0.28301302
Tricontane	97	0.38493044	0.56898284	0.49777271	0.61474654	0.42238982	0.26121066
Tricontane	137	0.71128451	0.28302037	0.35260708	0.27447932	0.19212444	0.29344246
Tricontane	158	0.43467387	0.6267191	0.30651528	0.55101397	0.31501945	0.48411978
Tricontane	181	0.3579891	0.335712	0.20989915	0.36553664	0.15566077	0.40474707
n-dotriacontane	0	1	1	1	1	1	1
n-dotriacontane	21	1.14698879	1.19707123	1.02798663	0.93895294	#VALUE!	0.94640244
n-dotriacontane	42	0.88891403	0.80316935	0.65865273	0.55498167	0.54764449	0.59119361
n-dotriacontane	75	0.59400729	0.54044118	0.42266788	0.2963083	0.21325517	0.30717267
n-dotriacontane	97	0.5467128	0.74400085	0.65290739	0.66436421	0.41299239	0.33062094
n-dotriacontane	137	0.79140497	0.35021514	0.38839357	0.3095303	0.2007029	0.34118937
n-dotriacontane	158	0.51493868	0.73947847	0.32609524	0.59276229	0.37988001	0.53658537
n-dotriacontane	181	0.47315589	0.43829996	0.27393753	0.41121705	0.21307663	0.52614451
Hexatricontane	0	1	1	1	1	1	1
Hexatricontane	21	1.01116117	1.2566168	0.92415655	0.85112571	#VALUE!	0.99695402
Hexatricontane	42	0.96608444	1.05789351	0.74946842	0.71887781	0.74790254	0.65937341
Hexatricontane	75	0.78549649	0.76893939	0.63625272	0.50875576	0.55917415	0.63759255
Hexatricontane	97	0.82726279	0.98555957	0.78309496	0.8180758	0.78424524	0.6690659
Hexatricontane	137	0.90150433	0.61641403	0.57302989	0.5449023	0.5040814	0.68067932
Hexatricontane	158	0.78284783	1.04617307	0.53554872	0.74306987	0.71041699	0.8584392
Hexatricontane	181	0.69520712	0.71082317	0.44579236	0.596968	0.43859771	0.7657377
n-hexatriaconta	0	1	1	1	1	1	1
n-hexatriaconta	21	0.92932766	0.88738865	0.67386415	0.54896455	#VALUE!	0.62965517
n-hexatriaconta	42	1.13588928	1.02748887	0.89222431	0.75448488	0.81478814	0.79403418
n-hexatriaconta	75	0.92554625	0.73888889	0.62691568	0.52086899	0.50765133	0.6587372
n-hexatriaconta	97	0.80099783	0.81764942	0.71691792	0.70929705	0.50911744	0.49492546
n-hexatriaconta	137	0.9005928	0.5218638	0.55072216	0.54955958	0.52513602	0.56276637
n-hexatriaconta	158	0.89240559	1.03404353	0.55603419	0.71351016	0.73321599	0.79854809
n-hexatriaconta	181	0.7372429	0.66231994	0.5244616	0.57724834	0.39971639	0.73292037

Appendix F Average Fraction of Compounds Remaining at Various Points in Time During Mesocosm Studies

		Treatment					
Day	Compound	ORC and Ammonium Nitrate	ORC and Meister	ORC	Ammonium Nitrate	Meister	Control Oil Only
0	Dodecane	1	1	1	1	1	1
43	Dodecane	0.63116553	0.37263866	0.63172414	0.28827635	0.32897789	0.37049782
71	Dodecane	0.27055415	0.33576407	0.20801822	0.18244686	0.19345319	0.23222865
133	Dodecane	0.0483244	0.05676971	0.09223404	0.01781837	0.00983345	0.01862866
0	Heptadecane	1	1	1	1	1	1
43	Heptadecane	0.48703408	0.41710911	0.51604774	0.27166499	0.47292588	0.31545523
71	Heptadecane	0.22690368	0.3326086	0.16022419	0.26045451	0.29312155	0.30123207
133	Heptadecane	0.09414905	0.11636103	0.13826084	0.02788678	0.08508621	0.10222263
0	Hexadecane	1	1	1	1	1	1
43	Hexadecane	0.56590161	0.50734854	0.61976633	0.31994458	0.54546191	0.59764672
71	Hexadecane	0.31597002	0.4153324	0.23536999	0.32128456	0.34419945	0.40641308
133	Hexadecane	0.06500982	0.07893239	0.12500217	0.01867977	0.05726768	0.07534974
0	n-dotriacontane	1	1	1	1	1	1
43	n-dotriacontane	1.08389274	0.91570846	1.02500865	0.72020216	0.9698273	0.9838892
71	n-dotriacontane	0.61597283	0.67802536	0.27736122	0.43670608	0.57961156	0.5707322
133	n-dotriacontane	0.07670747	0.10405385	0.26231932	0.0369481	0.06524655	0.07126263
0	n-eicosane	1	1	1	1	1	1
43	n-eicosane	0.64720077	0.61277843	0.75884562	0.41073365	0.60290852	0.71037953
71	n-eicosane	0.34423805	0.53532108	0.24304458	0.3237635	0.38303419	0.26251831
133	n-eicosane	0.10103539	0.11519334	0.19661107	0.04500287	0.09688439	0.10439497
0	n-hexatriacontane	1	1	1	1	1	1
43	n-hexatriacontane	1.45593188	1.39904368	1.2029462	1.10856164	1.39947922	0.59535141
71	n-hexatriacontane	0.65895361	0.97584978	0.68515886	0.50020301	0.68765124	0.92030182
133	n-hexatriacontane	0.14016799	0.31917668	0.39938291	0.08136932	0.16088684	0
0	n-octacosane	1	1	1	1	1	1
43	n-octacosane	1.04228648	0.64532698	0.88609389	0.46495903	0.72612426	0.73853907
71	n-octacosane	0.43154358	0.5474343	0.23893406	0.3542733	0.42524159	0.33512898
133	n-octacosane	0.09545044	0.11790604	0.21667405	0.0494265	0.0730276	0.04054763
0	n-tetracosane	1	1	1	1	1	1
43	n-tetracosane	0.53138851	0.47760451	0.59757222	0.32845426	0.48335558	0.43978935
71	n-tetracosane	0.28542509	0.37340582	0.20734323	0.25354199	0.28033696	0.20476637
133	n-tetracosane	0.05498301	0.06582203	0.12214618	0.02597687	0.0453742	0.03350955
0	Octadecane	1	1	1	1	1	1
43	Octadecane	0.87718652	0.82276712	1.00882495	0.5242047	0.86586289	0.83169185
71	Octadecane	0.42513482	0.68377882	0.38667941	0.48349499	0.53473405	0.42517568
133	Octadecane	0.08412436	0.09960432	0.23073071	0.02990257	0.07278674	0.08748312
0	Pentadecane	1	1	1	1	1	1
43	Pentadecane	0.65327474	0.39773341	0.72779956	0.25312622	0.61548746	0.67426431
71	Pentadecane	0.39792768	0.48217818	0.29772387	0.36741863	0.39062405	0.47925645
133	Pentadecane	0.06802058	0.08558569	0.14523052	0.02769084	0.05994584	0.07631121
0	Pristane	1	1	1	1	1	1

		Treatment					
Day	Compound	ORC and Ammonium Nitrate	ORC and Meister	ORC	Ammonium Nitrate	Meister	Control Oil Only
43	Pristane	0.6402983	0.71551927	0.85930719	0.72072725	0.70303455	0.9376759
71	Pristane	0.65793704	0.74407486	0.59975896	0.69819631	0.71474552	0.68315458
133	Pristane	0.90771867	1.15897722	0.96800592	1.04200443	1.61458219	1.83303697
0	Tetradecane	1	1	1	1	1	1
43	Tetradecane	0.75724599	0.64397421	0.77364645	0.36268164	0.66537179	0.68799774
71	Tetradecane	0.39958367	0.52016509	0.27315218	0.35683104	0.43896884	0.51131413
133	Tetradecane	0.06549636	0.08289015	0.13284304	0.02132551	0.04181723	0.06011938
0	Tridecane	1	1	1	1	1	1
43	Tridecane	0.61025046	0.43606337	0.58720816	0.27975386	0.44380372	0.35278603
71	Tridecane	0.27207448	0.35199932	0.21703215	0.23210288	0.24921933	0.29584115
133	Tridecane	0.04734267	0.05614413	0.0928411	0.01587233	0.01594508	0.02480407
0	Undecane	1	1	1	1	1	1
43	Undecane	0.56123321	0.27551491	0.45449527	0.23719151	0.16727407	0.22828315
71	Undecane	0.17700738	0.27365386	0.15602866	0.09153774	0.10085152	0.12159135
133	Undecane	0.04414736	0.04732049	0.07224309	0.01462356	0.00603577	0.014617

Appendix G Kinetic Parameters Determined from Curve Fitting of Fraction of Alkane Components Remaining vs Time in Field Plots

Note: Treatment averages and standard deviations weighted according to the recirocal of the standard errors in the plots.

			1st Order				RECAL					
			kinetic k				kinetic k'		fraction degradable			
Compound	Treatment	Plot	a	SE	r^2	F	a	SE	b	SE	r^2	F
Dodecane	Oiled	A2	0.00716	0.0027	0.545	8.38	0.00722	0.0165	1	1.37	0.545	7.18
Dodecane	Oiled	B2	0.00356	0.000518	0.762	22.4	0.0109	0.00869	0.496	0.189	0.798	23.7
Dodecane	Oiled	C2	0.00999	0.00147	0.874	41.7	0.00997	0.0064	1	0.318	0.874	34.8
Dodecane	Oiled	D2	0.00161	0.000986	2.27E-01	2.05E+00	0.00161	0.0334	1	18.6	0.227	1.76
Dodecane	Oiled	E2	0.00277	0.0023	0.0974	0.756	0.00829	0.0517	0.467	1.62	0.0988	0.657
Dodecane	Oiled	F2	0.00191	0.0014	0.251	2.35	0.00191	0.0398	1	18.1	0.251	2.01
Dodecane	Oiled	G2	no fit				no fit					
Dodecane	Oiled	H2	0.00451	0.00195	0.371	4.13	0.00451	0.021	0.999	3.34	0.371	3.54
Dodecane	Oiled	I2	0.00722	0.00348	0.448	5.69	0.0072	0.0211	1	1.75	0.448	4.88
Dodecane	Oiled	J2	0.00778	0.00232	0.547	7.26	0.0106	0.0153	0.849	0.584	0.551	6.14
Dodecane	Oiled	AVERAGE	0.00443295			10.524	0.00839061		0.73911588			9.40744444
Dodecane	Oiled	Std Dev	0.0026898				0.00288985		0.23845638			
Dodecane	Ammonium Nit	A3	0.00532	0.00391	0.0443	0.324	0.00536	0.0343	1	4.35	0.0443	0.278
Dodecane	Ammonium Nit	B3	0.00407	0.000787	0.701	14.1	0.00407	0.01	0.999	1.82	0.701	11.7
Dodecane	Ammonium Nit	C3	0.00429	0.00143	0.501	7.02	0.00429	0.0163	1	2.78	0.501	6.02
Dodecane	Ammonium Nit	D3	0.00657	0.00177	5.43E-01	8.33E+00	0.0118	0.0146	0.73	0.408	0.552	7.38
Dodecane	Ammonium Nit	E3	0.00699	0.0014	0.727	18.7	0.00699	0.00887	1	0.769	0.727	16
Dodecane	Ammonium Nit	F3	0.00685	0.00165	0.6	10.5	0.0149	0.0141	0.681	0.251	0.63	10.2
Dodecane	Ammonium Nit	G3	0.00509	0.00159	0.4	4.01	0.00806	0.0174	0.752	0.91	0.402	3.36
Dodecane	Ammonium Nit	H3	0.0027	0.00191	0.208	1.84	0.00273	0.0368	1	11.1	0.208	1.58
Dodecane	Ammonium Nit	I3	0.0154	0.00218	0.91	60.7	0.0166	0.00613	0.968	0.119	0.911	51.1
Dodecane	Ammonium Nit	J3	0.00589	0.00097	0.703	16.6	0.019	0.00982	0.574	0.0971	0.822	27.7
Dodecane	Ammonium Nit	AVERAGE	0.00594384			14.2124	0.01093023		0.76145396			13.5318

			1st Order				RECAL					
			kinetic k				kinetic k'		fraction degradable			
Compound	Treatment	Plot	a	SE	r^2	F	a	SE	b	SE	r^2	F
Dodecane	Ammonium Nit	Std Dev	0.00285288				0.00566348		0.17613161			
Dodecane	Meister 70	A4	0.0112	0.00277	0.805	16.5	0.0214	0.0152	0.788	0.157	0.85	17
Dodecane	Meister 70	B4	0.00796	0.00235	0.531	7.91	0.00796	0.0137	0.999	0.906	0.631	6.78
Dodecane	Meister 70	C4	0.00726	0.002466	0.312	3.18	0.00728	0.0148	1	1.21	0.312	2.72
Dodecane	Meister 70	D4	0.00791	0.00113	8.79E-01	5.08E+01	0.00796	0.00613	1	0.439	0.879	43.5
Dodecane	Meister 70	E4	0.00503	0.00136	0.386	4.39	0.0118	0.0162	0.615	0.381	0.396	3.93
Dodecane	Meister 70	F4	0.00623	0.00133	0.662	13.7	0.00623	0.00965	1	0.989	0.662	11.8
Dodecane	Meister 70	G4	0.00788	0.00157	0.805	28.9	0.00788	0.00859	1	0.624	0.805	24.8
Dodecane	Meister 70	H4	0.00615	0.00205	0.533	7.99	0.00617	0.0151	1	1.57	0.533	6.85
Dodecane	Meister 70	I4	0.0132	0.00341	0.625	9.99	0.0351	0.0151	0.758	0.0947	0.773	17
Dodecane	Meister 70	J4	0.00954	0.00225	0.575	9.45	0.0282	0.0156	0.674	0.0953	0.771	20.2
Dodecane	Meister 70	AVERAGE	0.00771886			15.281	0.01251642		0.77768335			15.458
Dodecane	Meister 70	Std Dev	0.0020588				0.00913755		0.12166724			
Tridecane	Oiled	A2	0.00903	0.00264	0.657	13.4	0.00903	0.0122	1	0.719	0.657	11.5
Tridecane	Oiled	B2	0.00365	0.000467	0.817	31.3	0.0082	0.00717	0.582	0.285	0.832	29.7
Tridecane	Oiled	C2	0.00989	0.00127	0.906	58	0.0101	0.00559	1	0.272	0.906	48.1
Tridecane	Oiled	D2	0.00223	0.000908	0.35	3.77	0.00225	0.0217	1	8.18	0.35	3.23
Tridecane	Oiled	E2	0.00559	0.00232	0.266	2.53	0.02	0.0327	0.55	0.286	0.313	2.73
Tridecane	Oiled	F2	0.00267	0.00111	0.442	5.65	0.0027	0.0217	1	6.57	0.442	4.76
Tridecane	Oiled	G2	NO FIT		NO FIT		NO FIT		NO FIT		NO FIT	
Tridecane	Oiled	H2	0.00773	0.00171	0.714	17.5	0.0107	0.0106	0.839	0.402	0.72	15.4
Tridecane	Oiled	I2	0.0101	0.003	0.637	12.3	0.0105	0.00572	1	0.289	0.636	10.5
Tridecane	Oiled	J2	0.00737	0.00205	0.578	8.21	0.00855	0.0135	0.918	0.784	0.579	6.86
Tridecane	Oiled	AVERAGE	0.0052859			16.9622222	0.00924466		0.81884887			14.7533333
Tridecane	Oiled	Std Dev	0.00283793				0.00314412		0.19601807			
Tridecane	Ammonium Nit	A3	0.00388	0.00224	0.171	1.45	0.0039	0.0287	1	5.53	0.171	1.24
Tridecane	Ammonium Nit	B3	0.00463	0.000809	0.735	16.7	0.00563	0.00916	0.874	0.943	0.736	13.9
Tridecane	Ammonium Nit	C3	0.00532	0.00126	0.615	11.2	0.00533	0.0111	1	1.41	0.615	9.58
Tridecane	Ammonium Nit	D3	0.0067	0.00168	0.566	9.11	0.0136	0.0144	0.698	0.304	0.58	8.28

			1st Order				RECAL					
			kinetic k				kinetic k'		fraction degradable			
Compound	Treatment	Plot	a	SE	r^2	F	a	SE	b	SE	r^2	F
Tridecane	Ammonium Nit	E3	0.00663	0.00136	0.723	18.3	0.00666	0.00915	1	0.852	0.723	15.7
Tridecane	Ammonium Nit	F3	0.00668	0.00145	0.666	13.9	0.0119	0.0116	0.735	0.323	0.679	12.7
Tridecane	Ammonium Nit	G3	0.00591	0.00158	0.469	5.3	0.0173	0.0206	0.599	0.238	0.501	5.02
Tridecane	Ammonium Nit	H3	0.00539	0.00178	0.469	6.18	0.00664	0.0161	0.873	1.31	0.469	5.31
Tridecane	Ammonium Nit	I3	0.0183	0.0019	0.959	142	0.0208	0.00467	0.958	0.0614	0.962	127
Tridecane	Ammonium Nit	J3	0.00541	0.000831	0.688	15.5	0.0205	0.00923	0.535	0.0755	0.841	31.6
Tridecane	Ammonium Nit	AVERAGE	0.00647614			23.964	0.01271873		0.75975592			23.033
Tridecane	Ammonium Nit	Std Dev	0.00336792				0.00663971		0.18917847			
Tridecane	Meister 70	A4	0.00599	0.00134	0.788	14.9	0.00603	0.0111	1	1.17	0.788	11.2
Tridecane	Meister 70	B4	0.00775	0.0022	0.546	8.41	0.00822	0.0125	0.966	0.82	0.546	7.22
Tridecane	Meister 70	C4	0.0061	0.00186	0.361	3.95	0.00612	0.0139	1	1.46	0.361	3.39
Tridecane	Meister 70	D4	0.00729	0.00102	0.871	47.3	0.00732	0.00609	1	0.494	0.871	40.5
Tridecane	Meister 70	E4	0.00543	0.000891	0.734	19.3	0.0074	0.00816	0.822	0.535	0.736	16.8
Tridecane	Meister 70	F4	0.00684	0.00131	0.668	14.1	0.00795	0.00883	0.914	0.579	0.669	12.1
Tridecane	Meister 70	G4	0.00792	0.00119	0.873	47.9	0.00706	0.00696	1	0.595	0.861	37.3
Tridecane	Meister 70	H4	0.00651	0.00151	0.679	14.8	0.00858	0.0112	0.848	0.608	0.682	12.8
Tridecane	Meister 70	I4	0.00931	0.00168	0.716	15.1	0.0259	0.0148	0.699	0.0932	0.803	20.4
Tridecane	Meister 70	J4	0.00948	0.00204	0.602	10.6	0.0288	0.0133	0.67	0.0182	0.823	27.8
Tridecane	Meister 70	AVERAGE	0.00707545			19.636	0.01016567		0.71395389			18.951
Tridecane	Meister 70	Std Dev	0.00125571				0.00702944		0.09750307			
Tetradecane	Oiled	A2	0.00979	0.00238	0.718	17.8	0.0113	0.0106	0.929	0.407	0.72	15.4
Tetradecane	Oiled	B2	0.00242	0.000624	0.43	5.29	0.0157	0.0204	0.319	0.156	0.496	5.91
Tetradecane	Oiled	C2	0.00953	0.00107	0.923	71.7	0.00867	0.00529	1	0.328	0.913	52.5
Tetradecane	Oiled	D2	0.00287	0.000883	0.403	4.72	0.00288	0.0159	1	4.48	0.403	4.05
Tetradecane	Oiled	E2	0.00523	0.00217	0.293	2.9	0.0173	0.0302	0.548	0.334	0.327	2.91
Tetradecane	Oiled	F2	0.00257	0.00104	0.405	4.77	0.00259	0.0211	1	6.72	0.405	4.09
Tetradecane	Oiled	G2	NO FIT		NO FIT		0.1	0.298	0.405	0.123	0.199	1.49
Tetradecane	Oiled	H2	0.00799	0.00128	0.799	27.8	0.0106	0.00818	0.856	0.319	0.803	24.5
Tetradecane	Oiled	I2	0.00919	0.00277	0.562	8.98	0.0092	0.0125	1	0.715	0.562	7.7

			1st Order				RECAL					
			kinetic k				kinetic k'		fraction degradable			
Compound	Treatment	Plot	a	SE	r^2	F	a	SE	b	SE	r^2	F
Tetradecane	Oiled	J2	0.00624	0.00195	0.494	5.85	0.00677	0.0153	0.95	1.312	0.494	4.87
Tetradecane	Oiled	AVERAGE	0.00527253			16.6455556	0.00958973		0.60916323			12.342
Tetradecane	Oiled	Std Dev	0.002986				0.00708396		0.27410125			
Tetradecane	Ammonium Nit	A3	0.00682	0.00258	0.37	4.12	0.00701	0.0169	0.984	1.44	0.37	3.52
Tetradecane	Ammonium Nit	B3	0.004	0.00797	0.698	13.9	0.00372	0.011	1	2.25	0.69	11.1
Tetradecane	Ammonium Nit	C3	0.00512	0.00119	0.591	10.1	0.00516	0.0109	1	1.45	0.591	8.66
Tetradecane	Ammonium Nit	D3	0.0086	0.00233	0.558	8.85	0.0206	0.0172	0.696	0.182	0.626	10
Tetradecane	Ammonium Nit	E3	0.00641	0.00155	0.658	13.5	0.0065	0.0108	1	1.05	0.658	11.5
Tetradecane	Ammonium Nit	F3	0.0057	0.00124	0.627	11.8	0.00935	0.0113	0.742	0.469	0.638	10.6
Tetradecane	Ammonium Nit	G3	0.00564	0.0018	0.34	3.09	0.0203	0.0294	0.551	0.231	0.38	3.07
Tetradecane	Ammonium Nit	H3	0.00563	0.00139	0.554	8.71	0.0101	0.0132	0.714	0.47	0.563	7.73
Tetradecane	Ammonium Nit	I3	0.0165	0.00124	0.976	239	0.0193	0.00323	0.948	0.0482	0.979	237
Tetradecane	Ammonium Nit	J3	0.00406	0.000607	0.542	8.27	0.0279	0.00763	0.415	0.0292	0.92	68.8
Tetradecane	Ammonium Nit	AVERAGE	0.00675704			32.134	0.0144848		0.63960931			37.198
Tetradecane	Ammonium Nit	Std Dev	0.00370896				0.00797487		0.24002287			
Tetradecane	Meister 70	A4	0.0116	0.00209	0.916	43.8	0.0118	0.00785	0.992	0.289	0.916	32.9
Tetradecane	Meister 70	B4	0.00821	0.00243	0.568	9.19	0.00797	0.0127	1	0.905	0.569	7.92
Tetradecane	Meister 70	C4	0.00578	0.00193	0.364	4.01	0.00582	0.0153	1	1.73	0.364	3.44
Tetradecane	Meister 70	D4	0.0074	0.00138	0.791	26.5	0.00742	0.00825	1	0.648	0.791	22.7
Tetradecane	Meister 70	E4	0.00504	0.000722	0.738	19.7	0.0158	0.00873	0.551	0.113	0.807	25.1
Tetradecane	Meister 70	F4	0.00691	0.00112	0.724	18.4	0.011	0.00821	0.776	0.275	0.736	16.7
Tetradecane	Meister 70	G4	0.0072	0.00101	0.877	50.1	0.00729	0.00616	1	0.502	0.877	42.9
Tetradecane	Meister 70	H4	0.00709	0.00127	0.755	21.6	0.0129	0.00095	0.733	0.23	0.775	20.7
Tetradecane	Meister 70	I4	0.00722	0.00133	0.685	13	0.0122	0.0105	0.763	0.282	0.697	11.5
Tetradecane	Meister 70	J4	0.0101	0.00201	0.643	12.6	0.0298	0.0113	0.683	0.0642	0.868	39.4
Tetradecane	Meister 70	AVERAGE	0.00720681			21.89	0.01238892		0.73664688			22.326
Tetradecane	Meister 70	Std Dev	0.00169972				0.00445742		0.14554517			
Pentadecane	Oiled	A2	0.0101	0.00189	0.808	29.4	0.0118	0.00816	0.921	0.287	0.811	25.7
Pentadecane	Oiled	B2	0.00271	0.000668	0.604	10.7	0.00272	0.0129	0.999	3.88	0.604	9.14

			1st Order				RECAL					
			kinetic k				kinetic k'		fraction degradable			
Compound	Treatment	Plot	a	SE	r^2	F	a	SE	b	SE	r^2	F
Pentadecane	Oiled	C2	0.00928	0.000742	0.959	139	0.00907	0.00355	1	0.205	0.958	114
Pentadecane	Oiled	D2	0.00258	0.000932	0.39	4.47	0.0026	0.0189	0.998	6.01	0.39	3.83
Pentadecane	Oiled	E2	0.00586	0.00211	0.395	4.58	0.014	0.0218	0.64	0.401	0.424	4.41
Pentadecane	Oiled	F2	0.00347	0.0011	0.54	8.2	0.0035	0.0159	1	3.5	0.539	7.03
Pentadecane	Oiled	G2	NO FIT		NO FIT		0.1	0.272	0.404	0.112	0.248	1.97
Pentadecane	Oiled	H2	0.00814	0.00162	0.763	22.5	0.0122	0.00979	0.814	0.291	0.772	20.3
Pentadecane	Oiled	I2	0.0108	0.00247	0.658	13.5	0.0108	0.00917	1	0.404	0.658	11.6
Pentadecane	Oiled	J2	0.0071	0.00188	0.555	7.48	0.00851	0.013	0.898	0.749	0.559	6.35
Pentadecane	Oiled	AVERAGE	0.00592933			26.6477778	0.00925756		0.73792197			20.433
Pentadecane	Oiled	Std Dev	0.00309514				0.00662409		0.25072306			
Pentadecane	Ammonium Nit	A3	0.00497	0.0013	0.602	10.6	0.00504	0.0124	1	1.7	0.602	9.08
Pentadecane	Ammonium Nit	B3	0.00429	0.000703	0.696	13.7	0.0119	0.0105	0.55	0.214	0.74	14.3
Pentadecane	Ammonium Nit	C3	0.00504	0.000907	0.722	18.2	0.00506	0.0085	1	1.16	0.722	15.6
Pentadecane	Ammonium Nit	D3	0.0058	0.00171	0.489	6.7	0.00758	0.0143	0.851	0.939	0.49	5.77
Pentadecane	Ammonium Nit	E3	0.00461	0.0016	0.386	4.4	0.00405	0.0181	1	3.32	0.386	3.77
Pentadecane	Ammonium Nit	F3	0.00585	0.00138	0.605	10.7	0.0114	0.0131	0.685	0.367	0.623	9.92
Pentadecane	Ammonium Nit	G3	0.00609	0.00146	0.517	6.42	0.0193	0.02	0.587	0.186	0.567	6.54
Pentadecane	Ammonium Nit	H3	0.0054	0.00182	0.386	4.4	0.0125	0.0202	0.636	0.448	0.391	3.85
Pentadecane	Ammonium Nit	I3	0.0169	0.00132	0.973	215	0.0225	0.00299	0.912	0.0321	0.987	369
Pentadecane	Ammonium Nit	J3	0.00479	0.000814	0.663	13.8	0.0188	0.0111	0.508	0.0989	0.784	21.8
Pentadecane	Ammonium Nit	AVERAGE	0.00613321			30.392	0.01428897		0.76527847			45.963
Pentadecane	Ammonium Nit	Std Dev	0.00342474				0.00720041		0.17868554			
Pentadecane	Meister 70	A4	0.005	0.00144	0.725	10.5	0.00498	0.0149	1	2.06	0.725	7.9
Pentadecane	Meister 70	B4	0.00688	0.00139	0.73	18.9	0.00676	0.00903	1	0.823	0.73	16.2
Pentadecane	Meister 70	C4	0.00511	0.00178	0.3	3	0.00512	0.0165	0.999	2.22	0.3	2.57
Pentadecane	Meister 70	D4	0.0065	0.000996	0.847	38.7	0.00653	0.00687	1	0.658	0.847	33.1
Pentadecane	Meister 70	E4	0.00546	0.00088	0.782	25.1	0.00882	0.00835	0.747	0.382	0.788	22.3
Pentadecane	Meister 70	F4	0.00721	0.000826	0.883	52.6	0.00876	0.00528	0.893	0.291	0.885	46.1
Pentadecane	Meister 70	G4	0.00736	0.00151	0.792	26.7	0.00737	0.00896	1	0.72	0.792	22.9
Pentadecane	Meister 70	H4	0.00698	0.00144	0.725	18.4	0.0113	0.0106	0.772	0.338	0.732	16.4

			1st Order				RECAL					
			kinetic k				kinetic k'		fraction degradable			
Compound	Treatment	Plot	a	SE	r^2	F	a	SE	b	SE	r^2	F
Pentadecane	Meister 70	I4	0.00708	0.00182	0.489	5.74	0.0245	0.0263	0.619	0.163	0.508	5.17
Pentadecane	Meister 70	J4	0.00918	0.00189	0.693	15.8	0.022	0.0121	0.701	0.115	0.793	23
Pentadecane	Meister 70	AVERAGE	0.00659896			21.544	0.00950916		0.77018217			19.564
Pentadecane	Meister 70	Std Dev	0.00108574				0.00515392		0.13180439			
Hexadecane	Oiled	A2	0.0101	0.00229	0.754	21.4	0.0123	0.00998	0.912	0.327	0.757	18.7
Hexadecane	Oiled	B2	0.00286	0.000733	0.58	9.67	0.00517	0.0143	0.641	1.21	0.581	8.31
Hexadecane	Oiled	C2	0.00913	0.000711	0.96	145	0.00915	0.00344	1	0.196	0.96	121
Hexadecane	Oiled	D2	0.00246	0.000899	0.417	5	0.00247	0.0193	1	6.49	0.417	4.28
Hexadecane	Oiled	E2	0.00641	0.002	0.49	6.73	0.0141	0.0183	0.672	0.353	0.515	6.38
Hexadecane	Oiled	F2	0.00353	0.00107	0.56	8.89	0.00303	0.0173	1	4.57	0.545	7.19
Hexadecane	Oiled	G2	NO FIT		NO FIT		0.1	0.235	0.435	0.104	0.315	2.76
Hexadecane	Oiled	H2	0.00774	0.00172	0.737	19.7	0.0102	0.0105	0.861	0.441	0.74	17.1
Hexadecane	Oiled	I2	0.0115	0.00247	0.686	15.3	0.0118	0.00865	0.986	0.326	0.687	13.2
Hexadecane	Oiled	J2	0.00712	0.00169	0.615	9.59	0.0106	0.0127	0.806	0.461	0.622	8.21
Hexadecane	Oiled	AVERAGE	0.00596847			26.8088889	0.0097105		0.73708237			20.713
Hexadecane	Oiled	Std Dev	0.00306849				0.00690659		0.23394683			
Hexadecane	Ammonium Nit	A3	0.00569	0.00113	0.726	18.5	0.00578	0.00912	1	1.04	0.726	15.9
Hexadecane	Ammonium Nit	B3	0.00482	0.000657	0.779	21.2	0.012	0.00821	0.597	0.18	0.822	23.1
Hexadecane	Ammonium Nit	C3	0.0056	0.000891	0.761	22.3	0.00564	0.00735	1	0.867	0.761	19.1
Hexadecane	Ammonium Nit	D3	0.00553	0.00163	0.502	7.06	0.00566	0.0136	0.995	1.59	0.502	6.05
Hexadecane	Ammonium Nit	E3	0.00511	0.00134	0.597	10.4	0.00514	0.0124	1	1.66	0.596	8.87
Hexadecane	Ammonium Nit	F3	0.00576	0.0014	0.62	11.4	0.00896	0.0125	0.764	0.57	0.626	10.1
Hexadecane	Ammonium Nit	G3	0.00713	0.00164	0.557	7.54	0.0223	0.02	0.623	0.15	0.626	8.38
Hexadecane	Ammonium Nit	H3	0.00565	0.0017	0.421	5.09	0.0169	0.0207	0.59	0.259	0.442	4.75
Hexadecane	Ammonium Nit	I3	0.0161	0.00109	0.978	273	0.0211	0.00239	0.914	0.0291	0.99	510
Hexadecane	Ammonium Nit	J3	0.00498	0.000878	0.673	14.4	0.0168	0.0112	0.538	0.129	0.758	18.8
Hexadecane	Ammonium Nit	AVERAGE	0.00655818			39.089	0.01380336		0.79006136			62.505
Hexadecane	Ammonium Nit	Std Dev	0.00329235				0.00683853		0.16462024			
Hexadecane	Meister 70	A4	0.0054	0.00143	0.776	13.9	0.00555	0.0134	1	1.59	0.775	10.3

			1st Order				RECAL					
			kinetic k				kinetic K'		fraction degradable			
Compound	Treatment	Plot	a	SE	r^2	F	a	SE	b	SE	r^2	F
Hexadecane	Meister 70	B4	0.00712	0.00135	0.76	22.2	0.00759	0.00849	0.962	0.627	0.761	19.1
Hexadecane	Meister 70	C4	0.00509	0.00163	0.362	3.97	0.00511	0.0151	1	2.04	0.361	3.39
Hexadecane	Meister 70	D4	0.00617	0.00107	0.812	30.3	0.00619	0.00785	1	0.811	0.812	26
Hexadecane	Meister 70	E4	0.00562	0.00102	0.744	20.3	0.00946	0.00957	0.734	0.384	0.75	18
Hexadecane	Meister 70	F4	0.00679	0.00108	0.814	30.6	0.00726	0.00715	0.96	0.564	0.814	26.3
Hexadecane	Meister 70	G4	0.00755	0.00149	0.802	28.4	0.00627	0.00966	1	0.981	0.781	21.3
Hexadecane	Meister 70	H4	0.00669	0.0015	0.688	15.4	0.012	0.0121	0.733	0.33	0.698	13.9
Hexadecane	Meister 70	I4	0.00748	0.00182	0.535	6.9	0.0237	0.0228	0.648	0.159	0.565	6.49
Hexadecane	Meister 70	J4	0.00849	0.00196	0.657	13.4	0.0211	0.0146	0.686	0.146	0.73	16.3
Hexadecane	Meister 70	AVERAGE	0.00654217			18.537	0.00922007		0.76490622			16.108
Hexadecane	Meister 70	Std Dev	0.00095056				0.00514115		0.13280301			
Heptadecane	Oiled	A2	0.0104	0.00206	0.809	29.7	0.0108	0.00813	0.978	0.351	0.81	25.6
Heptadecane	Oiled	B2	0.00651	0.00179	0.685	15.2	0.00663	0.0123	1	1.151	0.684	13
Heptadecane	Oiled	C2	0.00929	0.000835	0.95	113	0.00946	0.00396	1	0.214	0.949	93.4
Heptadecane	Oiled	D2	0.00159	0.000999	0.265	2.52	0.0016	0.0345	1	19.2	0.265	2.16
Heptadecane	Oiled	E2	0.00669	0.00189	0.545	8.38	0.0151	0.017	0.667	0.287	0.574	8.1
Heptadecane	Oiled	F2	0.00362	0.00107	0.577	9.56	0.0036	0.0149	1	3.17	0.577	8.19
Heptadecane	Oiled	G2	no fit				0.1	0.201	0.491	0.101	0.381	3.7
Heptadecane	Oiled	H2	0.00948	0.00172	0.825	33	0.0107	0.00784	0.938	0.33	0.826	28.5
Heptadecane	Oiled	I2	0.0114	0.00257	0.664	13.8	0.0137	0.00974	0.923	0.268	0.666	12
Heptadecane	Oiled	J2	0.00766	0.00157	0.699	14	0.0104	0.0105	0.849	0.414	0.704	11.9
Heptadecane	Oiled	AVERAGE	0.00683453			26.5733333	0.01028664		0.7732332			20.655
Heptadecane	Oiled	Std Dev	0.00316545				0.00721924		0.21376019			
Heptadecane	Ammonium Nit	A3	0.00619	0.00118	0.765	22.8	0.00592	0.00888	1	0.978	0.763	19.4
Heptadecane	Ammonium Nit	B3	0.00597	0.000795	0.834	30.1	0.00837	0.00698	0.815	0.373	0.839	26.1
Heptadecane	Ammonium Nit	C3	0.00677	0.00101	0.829	33.9	0.00675	0.00666	1	0.608	0.829	29.1
Heptadecane	Ammonium Nit	D3	0.00645	0.00156	0.627	11.8	0.00658	0.0109	0.988	1.023	0.627	10.1
Heptadecane	Ammonium Nit	E3	0.00629	0.00207	0.636	12.2	0.00649	0.0147	1	1.42	0.635	10.4
Heptadecane	Ammonium Nit	F3	0.00814	0.00138	0.856	41.6	0.00831	0.00719	1	0.482	0.856	35.6

			1st Order				RECAL					
			kinetic k				kinetic K'		fraction degradable			
Compound	Treatment	Plot	a	SE	r^2	F	a	SE	b	SE	r^2	F
Heptadecane	Ammonium Nit	G3	0.0089	0.00159	0.736	16.7	0.0206	0.0121	0.717	0.12	0.799	19.8
Heptadecane	Ammonium Nit	H3	0.00629	0.00228	0.442	5.55	0.00631	0.0163	1	1.65	0.442	4.76
Heptadecane	Ammonium Nit	I3	0.0158	0.00103	0.98	300	0.0182	0.00275	0.949	0.0454	0.984	300
Heptadecane	Ammonium Nit	J3	0.0053	0.00082	0.757	21.9	0.0124	0.00882	0.622	0.194	0.788	22.3
Heptadecane	Ammonium Nit	AVERAGE	0.00764311			49.655	0.01145941		0.86870467			47.756
Heptadecane	Ammonium Nit	Std Dev	0.00314506				0.00539216		0.13077974			
Heptadecane	Meister 70	A4	0.00634	0.00145	0.837	20.6	0.0065	0.0111	1	1.06	0.837	15.4
Heptadecane	Meister 70	B4	0.0076	0.00144	0.785	25.6	0.00763	0.00818	0.999	0.624	0.785	21.9
Heptadecane	Meister 70	C4	0.00508	0.00129	0.451	5.74	0.00512	0.0138	1	1.86	0.451	4.92
Heptadecane	Meister 70	D4	0.00618	0.00118	0.786	25.7	0.00622	0.00866	1	0.89	0.786	22
Heptadecane	Meister 70	E4	0.0055	0.000969	0.781	25	0.00551	0.0082	1	0.998	0.781	21.4
Heptadecane	Meister 70	F4	0.00657	0.00116	0.799	27.9	0.00659	0.00791	0.999	0.747	0.799	23.9
Heptadecane	Meister 70	G4	0.00704	0.00154	0.779	24.6	0.00675	0.0098	1	0.895	0.777	20.9
Heptadecane	Meister 70	H4	0.00665	0.00137	0.728	18.8	0.0102	0.0104	0.784	0.395	0.736	16.7
Heptadecane	Meister 70	I4	0.00739	0.00163	0.601	9.05	0.014	0.0134	0.734	0.274	0.616	8.02
Heptadecane	Meister 70	J4	0.00856	0.00191	0.691	15.7	0.0178	0.0126	0.72	0.176	0.744	17.5
Heptadecane	Meister 70	AVERAGE	0.0065532			19.869	0.00823281		0.84066771			17.264
Heptadecane	Meister 70	Std Dev	0.00093155				0.00361417		0.12921348			
Pristane	Oiled	A2	0.000689	0.000482	0.148	1.22	0.000692	0.0403	1	55.3	0.148	1.04
Pristane	Oiled	B2	0.000393	0.000725	0.0383	0.279	0.000406	0.108	0.973	250	0.0383	0.239
Pristane	Oiled	C2	0.000564	0.000481	0.125	0.86	0.000568	0.0515	1	86.9	0.125	0.717
Pristane	Oiled	D2	0.000357	0.000582	0.0491	0.361	0.000578	0.0971	0.623	100	0.0487	0.307
Pristane	Oiled	E2	0.00175	0.000838	0.296	2.95	0.00176	0.0261	1	13	0.296	2.53
Pristane	Oiled	F2	0.000814	0.000828	0.115	0.909	0.000822	0.0579	0.999	66.2	0.115	0.779
Pristane	Oiled	G2	NO FIT		NO FIT		NO FIT		NO FIT		NO FIT	
Pristane	Oiled	H2	0.000281	0.000769	0.0196	0.14	0.000284	0.161	0.991	552	0.0196	0.12
Pristane	Oiled	I2	NO FIT		NO FIT		NO FIT		NO FIT		NO FIT	
Pristane	Oiled	J2	0.00226	0.00107	0.237	1.86	0.00227	0.0265	1	9.83	0.237	1.55
Pristane	Oiled	AVERAGE	0.00078289			1.072375	0.00126723		0.98365361			0.91025

			1st Order				RECAL					
			kinetic k				kinetic k'		fraction degradable			
Compound	Treatment	Plot	a	SE	r^2	F	a	SE	b	SE	r^2	F
Pristane	Oiled	Std Dev	0.00058895				0.00072625		0.07542211			
Pristane	Ammonium Nit	A3	0.00103	0.000782	0.171	1.45	0.00103	0.0432	1	38.9	0.171	1.24
Pristane	Ammonium Nit	B3	0.00167	0.000487	0.222	1.71	0.024	0.0389	0.212	0.0866	0.353	2.73
Pristane	Ammonium Nit	C3	0.00293	0.000504	0.7	16.3	0.00294	0.0089	1	2.44	0.7	14
Pristane	Ammonium Nit	D3	0.00178	0.00119	0.171	1.44	0.00179	0.0363	1	17.8	0.171	1.24
Pristane	Ammonium Nit	E3	0.00272	0.000799	0.533	8	0.00274	0.0153	1	4.57	0.533	6.85
Pristane	Ammonium Nit	F3	0.00105	0.0007	0.218	1.95	0.00105	0.0378	0.997	33.1	0.218	1.68
Pristane	Ammonium Nit	G3	NO FIT		NO FIT		0.0762	1.08	0.123	0.0946	0.0359	0.186
Pristane	Ammonium Nit	H3	0.0011	0.000774	0.0046	0.0323	0.0011	0.04	0.996	33.3	0.00458	0.0276
Pristane	Ammonium Nit	I3	0.00401	0.00102	0.343	3.13	0.0315	0.0419	0.409	0.106	0.459	4.25
Pristane	Ammonium Nit	J3	0.00148	0.000379	0.465	6.09	0.00901	0.0175	0.261	0.271	0.488	5.71
Pristane	Ammonium Nit	AVERAGE	0.00190705			4.45581111	0.00668888		0.25936254			3.79136
Pristane	Ammonium Nit	Std Dev	0.0008832				0.00920016		0.1541917			
Pristane	Meister 70	A4	NO FIT		NO FIT		NO FIT		NO FIT		NO FIT	
Pristane	Meister 70	B4	0.00255	0.000495	0.667	14	0.00492	0.0109	0.604	0.935	0.67	12.2
Pristane	Meister 70	C4	0.000434	0.00116	0.00241	0.0169	0.000403	0.168	1	403.6	0.00231	0.0139
Pristane	Meister 70	D4	0.00207	0.000592	0.531	7.92	0.00208	0.0154	0.999	6.34	0.531	6.79
Pristane	Meister 70	E4	0.00142	0.000609	0.389	4.45	0.00142	0.0239	1	15.1	0.389	3.81
Pristane	Meister 70	F4	0.00294	0.00087	0.509	7.25	0.00294	0.0154	1	4.21	0.509	6.21
Pristane	Meister 70	G4	0.00385	0.00385	0.765	22.8	0.00298	0.0112	1	3.028	0.693	13.6
Pristane	Meister 70	H4	0.00206	0.000597	0.414	4.94	0.0127	0.0216	0.3	0.222	0.448	4.87
Pristane	Meister 70	I4	0.000304	0.00114	0.00959	0.0581	0.00038	0.238	0.781	477	0.00944	0.0477
Pristane	Meister 70	J4	0.00238	0.00095	0.217	1.94	0.021	0.038	0.296	0.165	0.323	2.86
Pristane	Meister 70	AVERAGE	0.00195553			7.04166667	0.00516049		0.36899644			5.60017778
Pristane	Meister 70	Std Dev	0.00083614				0.00511997		0.18581126			
Octadecane	Oiled	A2	0.00983	0.00189	0.812	30.2	0.0102	0.008	0.98	0.379	0.812	25.9
Octadecane	Oiled	B2	0.003	0.000659	0.675	14.5	0.00301	0.0113	1	3.01	0.675	12.5
Octadecane	Oiled	C2	0.00847	0.000954	0.924	73.4	0.00875	0.00206	1	0.31	0.923	60.2
Octadecane	Oiled	D2	0.00214	0.000862	0.387	4.42	0.00216	0.0215	1	8.49	0.387	3.79

			1st Order				RECAL					
			kinetic k				kinetic k'		fraction degradable			
Compound	Treatment	Plot	a	SE	r^2	F	a	SE	b	SE	r^2	F
Octadecane	Oiled	E2	0.00644	0.00179	0.539	8.19	0.0147	0.0167	0.659	0.293	0.566	7.84
Octadecane	Oiled	F2	0.0034	0.00101	0.567	9.17	0.003	0.0167	0.999	4.46	0.556	7.51
Octadecane	Oiled	G2	no fit				0.1	0.26	0.431	0.114	0.269	2.21
Octadecane	Oiled	H2	0.00797	0.00158	0.793	26.7	0.00701	0.00913	1	0.789	0.78	21.3
Octadecane	Oiled	I2	0.0115	0.00277	0.635	12.2	0.012	0.00976	0.98	0.358	0.635	10.5
Octadecane	Oiled	J2	0.00674	0.00165	0.6	9	0.00676	0.0125	0.859	0.654	0.602	7.57
Octadecane	Oiled	AVERAGE	0.00558637			20.8644444	0.00864055		0.7334987			15.932
Octadecane	Oiled	Std Dev	0.00294798				0.00606609		0.2518906			
Octadecane	Ammonium Nit	A3	0.00609	0.00112	0.777	24.3	0.0062	0.00834	1	0.861	0.776	20.8
Octadecane	Ammonium Nit	B3	0.00494	0.000785	0.731	16.3	0.0113	0.0097	0.62	0.242	0.762	16
Octadecane	Ammonium Nit	C3	0.00627	0.000962	0.774	23.9	0.00629	0.00694	1	0.702	0.774	20.5
Octadecane	Ammonium Nit	D3	0.00559	0.00146	5.34E-01	8.03E+00	0.00711	0.0127	0.859	0.927	0.535	6.9
Octadecane	Ammonium Nit	E3	0.00595	0.00118	0.749	20.9	0.00598	0.00909	1	0.986	0.749	17.9
Octadecane	Ammonium Nit	F3	0.00522	0.00131	0.601	10.5	0.00866	0.0133	0.731	0.611	0.607	9.26
Octadecane	Ammonium Nit	G3	0.00856	0.00171	0.667	12	0.0228	0.0155	0.688	0.123	0.744	14.5
Octadecane	Ammonium Nit	H3	0.00641	0.00187	0.502	7.07	0.0122	0.0162	0.709	0.415	0.513	6.33
Octadecane	Ammonium Nit	I3	0.0242	0.00768	0.73	16.2	0.0986	0.24	0.823	0.0541	0.893	41.8
Octadecane	Ammonium Nit	J3	0.00409	0.000831	0.64	12.5	0.0108	0.0122	0.553	0.299	0.666	12
Octadecane	Ammonium Nit	AVERAGE	0.00598489			15.17	0.00972682		0.76254107			16.599
Octadecane	Ammonium Nit	Std Dev	0.0025942				0.00770159		0.11488551			
Octadecane	Meister 70	A4	0.00545	0.00151	0.779	14.1	0.0056	0.0138	1	1.63	0.778	10.5
Octadecane	Meister 70	B4	0.00634	0.00137	0.713	17.4	0.00636	0.00974	1	0.968	0.713	14.9
Octadecane	Meister 70	C4	0.00475	0.00131	0.431	5.31	0.00477	0.0132	1	1.96	0.431	4.55
Octadecane	Meister 70	D4	0.00594	0.00102	8.05E-01	2.90E+01	0.0059	0.00787	1	0.871	0.805	24.8
Octadecane	Meister 70	E4	0.00576	0.000851	0.818	31.5	0.00831	0.00737	0.799	0.395	0.822	27.8
Octadecane	Meister 70	F4	0.00632	0.00122	0.751	21.1	0.00689	0.00893	0.947	0.751	0.751	18.1
Octadecane	Meister 70	G4	0.00737	0.00115	0.859	42.7	0.007	0.00702	1	0.608	0.857	35.9
Octadecane	Meister 70	H4	0.00645	0.00128	0.717	17.7	0.0121	0.0107	0.712	0.281	0.735	16.7
Octadecane	Meister 70	I4	0.00794	0.00154	0.666	12	0.0188	0.0137	0.694	0.156	0.707	12.1
Octadecane	Meister 70	J4	0.00829	0.00181	0.685	15.2	0.0184	0.0126	0.701	0.162	0.749	17.9

			1st Order				RECAL					
			kinetic k				kinetic k'		fraction degradable			
Compound	Treatment	Plot	a	SE	r^2	F	a	SE	b	SE	r^2	F
Octadecane	Meister 70	AVERAGE	0.00636563			20.601	0.0089058		0.78314389			18.325
Octadecane	Meister 70	Std Dev	0.00098189				0.00446077		0.12336042			
Phytane	Oiled	A2	0.000886	0.000519	0.161	1.34	0.00089	0.0334	1	35.1	0.161	1.15
Phytane	Oiled	B2	0.00146	0.000654	0.26	2.46	0.00147	0.0248	0.999	15.1	0.26	2.11
Phytane	Oiled	C2	No Fit				No Fit					
Phytane	Oiled	D2	No fit				No fit					
Phytane	Oiled	E2	0.0017	0.00081	0.276	2.67	0.00171	0.026	1	13.4	0.276	2.29
Phytane	Oiled	F2	No fit				No fit					
Phytane	Oiled	G2	No fit				No fit					
Phytane	Oiled	H2	0.000622	0.000828	0.0394	0.287	0.000638	0.0772	0.976	113	0.0394	0.246
Phytane	Oiled	I2	No fit				No fit					
Phytane	Oiled	J2	0.00149	0.00114	0.118	0.804	0.0015	0.0442	1	26.5	0.118	0.67
Phytane	Oiled	AVERAGE	0.001195			1.5122	0.00134365		0.99870968			1.2932
Phytane	Oiled	Std Dev	0.00039908				0.00036258		0.00471684			
Phytane	Ammonium Nit	A3	0.000704	0.000777	0.113	0.889	0.000712	0.0631	0.999	84	0.113	0.762
Phytane	Ammonium Nit	B3	0.00126	0.000537	0.35	3.23	0.00126	0.025	1	18.1	0.35	2.69
Phytane	Ammonium Nit	C3	0.00345	0.000595	0.656	13.3	0.00345	0.00872	1	1.96	0.656	11.4
Phytane	Ammonium Nit	D3	0.0015	0.00102	1.32E-01	1.07E+00	0.00151	0.0376	1	22.2	0.132	0.915
Phytane	Ammonium Nit	E3	0.00339	0.000642	0.683	15.1	0.00339	0.00962	1	2.21	0.683	12.9
Phytane	Ammonium Nit	F3	0.00158	0.000606	0.335	3.52	0.00196	0.0213	0.827	7.78	0.335	3.02
Phytane	Ammonium Nit	G3	no fit				0.1	1.45	0.231	0.0868	0.214	1.36
Phytane	Ammonium Nit	H3	0.000175	0.000818	0.00674	0.0475	0.00112	0.322	0.147	38.8	0.0058	0.035
Phytane	Ammonium Nit	I3	0.0026	0.000915	0.257	2.07	0.0108	0.0261	0.39	0.441	0.268	1.83
Phytane	Ammonium Nit	J3	0.00172	0.000383	0.548	8.49	0.00171	0.0123	1	6.31	0.548	7.28
Phytane	Ammonium Nit	AVERAGE	0.00186134			5.30183333	0.00332425		0.32215949			4.2192
Phytane	Ammonium Nit	Std Dev	0.00102542				0.00443427		0.21574822			
Phytane	Meister 70	A4	No fit				No fit					
Phytane	Meister 70	B4	0.00229	0.000424	0.657	13.4	0.00331	0.0102	0.741	1.79	0.657	11.5
Phytane	Meister 70	C4	No fit				No fit					

			1st Order				RECAL					
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Compound	Treatment	Plot	a	SE	r^2	F	a	SE	b	SE	r^2	F
Phytane	Meister 70	D4	0.00219	0.000502	5.80E-01	9.66E+00	0.00369	0.0128	0.656	1.73	0.581	8.32
Phytane	Meister 70	E4	0.00199	0.00063	0.429	5.27	0.00202	0.0172	0.988	7.24	0.429	4.51
Phytane	Meister 70	F4	0.00224	0.000913	0.318	3.26	0.00632	0.0245	0.459	1.13	0.322	2.85
Phytane	Meister 70	G4	0.0031	0.000523	0.753	21.4	0.00312	0.00864	1	2.21	0.753	18.3
Phytane	Meister 70	H4	0.0013	0.000535	0.252	2.36	0.0123	0.0325	0.203	0.237	0.267	2.19
Phytane	Meister 70	I4	0.000331	0.00112	0.0092	0.0557	0.000336	0.207	0.993	598	0.0092	0.0464
Phytane	Meister 70	J4	0.0025	0.000975	0.0548	0.406	0.0306	0.0552	0.272	0.12	261	2.12
Phytane	Meister 70	AVERAGE	0.00208851			6.9764625	0.00513687		0.32394523			6.22955
Phytane	Meister 70	Std Dev	0.00069818				0.00581238		0.18688619			
Eicosane	Oiled	A2	0.00792	0.00143	0.817	31.4	0.00762	0.00785	1	0.6	0.816	26.7
Eicosane	Oiled	B2	0.00272	0.000684	0.62	11.5	0.00274	0.0131	0.998	3.91	0.621	9.85
Eicosane	Oiled	C2	0.00775	0.000698	0.943	99.6	0.0076	0.00416	1	0.318	0.943	82.2
Eicosane	Oiled	D2	0.00217	0.000802	4.13E-01	4.93E+00	0.00218	0.0198	1	7.72	0.413	4.23
Eicosane	Oiled	E2	0.00602	0.00162	0.548	8.5	0.0136	0.016	0.651	0.316	0.571	7.98
Eicosane	Oiled	F2	0.00327	0.00107	0.503	7.09	0.00329	0.0166	1	3.97	0.503	6.08
Eicosane	Oiled	G2	no fit				0.1	0.287	0.39	0.114	0.228	1.77
Eicosane	Oiled	H2	0.0076	0.00149	0.788	26.1	0.0076	0.00852	1	0.653	0.788	22.3
Eicosane	Oiled	I2	0.0109	0.00269	0.609	10.9	0.0115	0.0101	0.976	0.393	0.61	9.37
Eicosane	Oiled	J2	0.0064	0.0016	0.578	8.22	0.0083	0.0128	0.857	0.732	0.58	6.9
Eicosane	Oiled	AVERAGE	0.00536546			23.1377778	0.00785778		0.70595195			17.738
Eicosane	Oiled	Std Dev	0.00262277				0.00643362		0.27331163			
Eicosane	Ammonium Nit	A3	0.00604	0.000948	0.813	30.4	0.00612	0.00713	1	0.75	0.813	26
Eicosane	Ammonium Nit	B3	0.00489	0.000742	0.752	18.2	0.0107	0.00911	0.631	0.255	0.778	17.5
Eicosane	Ammonium Nit	C3	0.00594	0.00089	0.784	25.4	0.00597	0.00684	1	0.746	0.784	21.8
Eicosane	Ammonium Nit	D3	0.00551	0.00134	5.75E-01	9.45E+00	0.00572	0.0114	0.974	1.28	0.575	8.1
Eicosane	Ammonium Nit	E3	0.00601	0.0011	0.777	24.4	0.00602	0.00835	0.999	0.899	0.777	20.9
Eicosane	Ammonium Nit	F3	0.00506	0.0012	0.635	12.2	0.0076	0.0122	0.77	0.72	0.638	10.6
Eicosane	Ammonium Nit	G3	0.00853	0.00185	0.601	9.02	0.028	0.0203	0.659	0.105	0.732	13.7
Eicosane	Ammonium Nit	H3	0.00554	0.00171	0.446	5.65	0.0115	0.0178	0.662	0.468	0.457	5.04

			1st Order				RECAL					
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Compound	Treatment	Plot	a	SE	r^2	F	a	SE	b	SE	r^2	F
Eicosane	Ammonium Nit	I3	0.0151	0.00132	0.965	168	0.0156	0.00364	0.987	0.0829	0.966	140
Eicosane	Ammonium Nit	J3	0.00441	0.000775	0.685	15.2	0.0122	0.0106	0.553	0.213	0.719	15.4
Eicosane	Ammonium Nit	AVERAGE	0.00635696			31.792	0.0105272		0.7907568			27.904
Eicosane	Ammonium Nit	Std Dev	0.00277966				0.00536168		0.17869922			
Eicosane	Meister 70	A4	0.00488	0.00144	0.745	11.7	0.00501	0.0151	1	2.078	0.744	8.73
Eicosane	Meister 70	B4	0.00637	0.00124	0.742	20.2	0.00671	0.00887	0.968	0.792	0.742	17.3
Eicosane	Meister 70	C4	0.00455	0.0012	0.459	5.94	0.00457	0.0127	1	1.98	0.459	5.09
Eicosane	Meister 70	D4	0.00563	0.00093	8.10E-01	2.98E+01	0.00564	0.00764	1	0.902	0.81	25.5
Eicosane	Meister 70	E4	0.00548	0.000944	0.761	22.3	0.00939	0.00905	0.724	0.364	0.77	20.1
Eicosane	Meister 70	F4	0.00617	0.00127	0.734	19.4	0.0066	0.00947	0.958	0.856	0.734	16.6
Eicosane	Meister 70	G4	0.00719	0.00121	0.838	36.2	0.0073	0.00735	1	0.598	0.838	31
Eicosane	Meister 70	H4	0.00613	0.00122	0.702	16.5	0.0131	0.0112	0.668	0.243	0.73	16.2
Eicosane	Meister 70	I4	0.0067	0.00147	0.559	7.62	0.0193	0.0175	0.628	0.173	0.599	7.48
Eicosane	Meister 70	J4	0.00753	0.00177	0.646	12.8	0.0175	0.014	0.676	0.189	0.705	14.4
Eicosane	Meister 70	AVERAGE	0.00599117			18.246	0.00880089		0.74811129			16.24
Eicosane	Meister 70	Std Dev	0.00086025				0.00437791		0.14256075			
Docosane	Oiled	A2	0.0107	0.00263	0.761	22.3	0.0107	0.0099	1	0.445	0.761	19.1
Docosane	Oiled	B2	0.00287	0.000834	0.567	9.16	0.00287	0.0121	1	4.26	0.567	7.85
Docosane	Oiled	C2	0.00978	0.000804	0.96	146	0.00978	0.00358	1	0.183	0.96	122
Docosane	Oiled	D2	0.00272	0.000968	4.35E-01	5.40E+00	0.00272	0.0186	0.999	5.6	0.435	4.62
Docosane	Oiled	E2	0.00741	0.00208	0.556	8.76	0.0158	0.0166	0.696	0.273	0.585	8.46
Docosane	Oiled	F2	0.0041	0.00116	0.597	10.3	0.0041	0.0139	1	2.51	0.597	8.87
Docosane	Oiled	G2	No fit				0.094	0.176	0.507	0.104	0.38	3.67
Docosane	Oiled	H2	0.00958	0.00204	0.795	27.2	0.0096	0.00875	1	0.468	0.795	23.3
Docosane	Oiled	I2	0.014	0.00326	0.706	16.8	0.0169	0.01	0.931	0.197	0.71	14.7
Docosane	Oiled	J2	0.00834	0.00168	0.724	15.8	0.0108	0.01	0.875	0.384	0.728	13.4
Docosane	Oiled	AVERAGE	0.00660518			29.08	0.01016007		0.79348101			22.597
Docosane	Oiled	Std Dev	0.00348083				0.00763998		0.20980791			
Docosane	Ammonium Nit	A3	0.00688	0.00115	0.801	28.2	0.00688	0.00743	1	0.66	0.801	24.1

			1st Order				RECAL					
			kinetic k				kinetic k'		fraction degradable			
Compound	Treatment	Plot	a	SE	r^2	F	a	SE	b	SE	r^2	F
Docosane	Ammonium Nit	B3	0.0052	0.000836	0.725	15.9	0.0126	0.01	0.614	0.208	0.765	16.3
Docosane	Ammonium Nit	C3	0.00632	0.000931	0.801	28.1	0.00636	0.00664	1	0.661	0.801	24.1
Docosane	Ammonium Nit	D3	0.00636	0.0015	6.00E-01	1.05E+01	0.0108	0.0124	0.746	0.413	0.606	9.24
Docosane	Ammonium Nit	E3	0.00668	0.00121	0.791	26.5	0.00676	0.00808	1	0.736	0.791	22.7
Docosane	Ammonium Nit	F3	0.00602	0.00153	0.623	11.6	0.00963	0.0131	0.759	0.531	0.63	10.2
Docosane	Ammonium Nit	G3	0.0106	0.00201	0.742	17.3	0.0237	0.0132	0.751	0.106	0.815	22
Docosane	Ammonium Nit	H3	0.00777	0.00129	0.577	9.53	0.0117	0.0141	0.808	0.441	0.583	8.38
Docosane	Ammonium Nit	I3	0.0173	0.000831	0.991	640	0.0194	0.00188	0.96	0.0279	0.993	719
Docosane	Ammonium Nit	J3	0.00565	0.00101	0.702	16.5	0.0141	0.0106	0.617	0.188	0.743	17.3
Docosane	Ammonium Nit	AVERAGE	0.0080427			80.413	0.01380327		0.86166769			87.332
Docosane	Ammonium Nit	Std Dev	0.00388683				0.005748		0.13548464			
Docosane	Meister 70	A4	0.00648	0.00136	0.859	24.4	0.00681	0.0102	1	0.904	0.857	17.9
Docosane	Meister 70	B4	0.00729	0.00154	0.73	18 9	0.00799	0.00946	0.947	0.638	0.73	16.2
Docosane	Meister 70	C4	0.00519	0.00137	0.476	6.35	0.00521	0.0124	1	1.64	0.476	5.45
Docosane	Meister 70	D4	0.00631	0.00113	7.98E-01	2.76E+01	0.00634	0.00812	0.998	0.81	0.797	23.6
Docosane	Meister 70	E4	0.00615	0.00113	0.755	21.6	0.00983	0.00943	0.762	0.37	0.763	19.3
Docosane	Meister 70	F4	0.00656	0.00139	0.73	19	0.00727	0.00975	0.938	0.749	0.731	16.3
Docosane	Meister 70	G4	0.00779	0.00155	0.808	29.5	0.00779	0.00857	1	0.633	0.808	25.3
Docosane	Meister 70	H4	0.00722	0.00167	0.655	13.3	0.0153	0.0133	0.693	0.229	0.691	13.4
Docosane	Meister 70	I4	0.00943	0.00188	0.688	13.2	0.0228	0.015	0.723	0.125	0.745	14.6
Docosane	Meister 70	J4	0.00935	0.00125	0.665	13.9	0.0182	0.0141	0.745	0.196	0.713	14.9
Docosane	Meister 70	AVERAGE	0.00708627			18.775	0.00991036		0.79462693			16.695
Docosane	Meister 70	Std Dev	0.001281				0.00504397		0.11348176			
Tetracosane	Oiled	A2	0.0109	0.00251	0.783	25.3	0.0109	0.00923	0.998	0.4	0.783	21.7
Tetracosane	Oiled	B2	0.00275	0.000824	0.543	8.32	0.00276	0.0157	0.999	4.63	0.543	7.13
Tetracosane	Oiled	C2	0.00994	0.000526	0.982	326	0.00994	0.0023	1	0.115	0.982	271
Tetracosane	Oiled	D2	0.00243	0.00112	3.18E-01	3.26E+00	0.00245	0.0242	1	8.27	0.318	2.79
Tetracosane	Oiled	E2	0.00738	0.00212	0.548	8.48	0.0159	0.0171	0.693	0.275	0.577	8.2
Tetracosane	Oiled	F2	0.00429	0.00135	0.552	8.61	0.00433	0.0153	1	2.58	0.551	7.38

			1st Order				RECAL					
			kinetic k				kinetic k'		fraction degradable			
Compound	Treatment	Plot	a	SE	r^2	F	a	SE	b	SE	r^2	F
Tetracosane	Oiled	G2	0.0076	0.00251	0.0472	0.347	0.1	0.17	0.548	0.095	0.456	5.02
Tetracosane	Oiled	H2	0.0098	0.00198	0.802	28.3	0.0114	0.00879	0.925	0.33	0.803	24.5
Tetracosane	Oiled	I2	0.0138	0.00317	0.701	16.4	0.0176	0.0104	0.911	0.186	0.707	14.5
Tetracosane	Oiled	J2	0.0082	0.00178	0.668	12.1	0.0138	0.0123	0.78	0.274	0.684	10.8
Tetracosane	Oiled	AVERAGE	0.00707424			43.7117	0.01093644		0.80628387			37.302
Tetracosane	Oiled	Std Dev	0.00344918				0.00771183		0.18450747			
Tetracosane	Ammonium Nit	A3	0.00711	0.0012	0.785	25.6	0.00714	0.00741	1	0.623	0.785	22
Tetracosane	Ammonium Nit	B3	0.00503	0.00107	0.545	7.19	0.0183	0.0167	0.529	0.153	0.646	9.13
Tetracosane	Ammonium Nit	C3	0.00604	0.000894	0.812	30.3	0.0061	0.00673	0.999	0.71	0.812	25.9
Tetracosane	Ammonium Nit	D3	0.00628	0.00171	5.16E-01	7.48E+00	0.0129	0.0156	0.686	0.356	0.528	6.7
Tetracosane	Ammonium Nit	E3	0.00594	0.00125	0.735	19.4	0.00599	0.0096	1	1.04	0.735	16.6
Tetracosane	Ammonium Nit	F3	0.00588	0.00149	0.636	12.2	0.0868	0.0128	0.79	0.633	0.64	10.7
Tetracosane	Ammonium Nit	G3	0.0107	0.00208	0.718	15.3	0.0278	0.0151	0.731	0.087	0.83	24.4
Tetracosane	Ammonium Nit	H3	0.00719	0.00189	0 584	9.83	0.0124	0.014	0.753	0.371	0.595	8.8
Tetracosane	Ammonium Nit	I3	0.0178	0.00142	0.974	227	0.0227	0.00323	0.925	0.0346	0.985	322
Tetracosane	Ammonium Nit	J3	0.00593	0.00106	0.704	16.7	0.0158	0.0108	0.611	0.156	0.762	19.2
Tetracosane	Ammonium Nit	AVERAGE	0.00747784			37.1	0.0198427		0.80260464			46.543
Tetracosane	Ammonium Nit	Std Dev	0.0035318				0.01963468		0.14827643			
Tetracosane	Meister 70	A4	0.00667	0.00102	0.916	43.8	0.00681	0.00739	1	0.656	0.916	32.7
Tetracosane	Meister 70	B4	0.0074	0.00163	0.708	17	0.00936	0.0103	0.874	0.503	0.711	14.8
Tetracosane	Meister 70	C4	0.00501	0.00153	0.391	4.49	0.00503	0.0144	1	1.99	0.391	3.85
Tetracosane	Meister 70	D4	0.00616	0.00118	7.76E-01	2.42E+01	0.00553	0.00935	1	1.13	0.766	19.6
Tetracosane	Meister 70	E4	0.00601	0.00122	0.72	18	0.0101	0.0106	0.74	0.388	0.731	16.3
Tetracosane	Meister 70	F4	0.00651	0.00138	0.738	19.7	0.00709	0.00971	0.948	0.783	0.738	16.9
Tetracosane	Meister 70	G4	0.00788	0.00163	0.795	27.1	0.00799	0.00887	1	0.631	0.795	23.2
Tetracosane	Meister 70	H4	0.00724	0.00171	0.662	13.7	0.0137	0.0129	0.724	0.281	0.685	13.1
Tetracosane	Meister 70	I4	0.0134	0.00257	0.784	21.8	0.0273	0.0121	0.794	0.079	0.878	36.1
Tetracosane	Meister 70	J4	0.00909	0.00237	0.655	13.3	0.0174	0.0145	0.746	0.217	0.696	13.7
Tetracosane	Meister 70	AVERAGE	0.0071196			20.309	0.0104146		0.81558071			19.025
Tetracosane	Meister 70	Std Dev	0.00184219				0.00616298		0.09043689			

			1st Order				RECAL					
			kinetic k				kinetic k'		fraction degradable			
Compound	Treatment	Plot	a	SE	r^2	F	a	SE	b	SE	r^2	F
Hexacosane	Oiled	A2	0.01	0.00189	0.836	35.7	0.00994	0.00769	1	0.389	0.836	30.6
Hexacosane	Oiled	B2	0.00312	0.000762	0.648	12.9	0.00314	0.0125	0.998	3.16	0.648	11
Hexacosane	Oiled	C2	0.0128	0.00213	0.862	37.3	0.0154	0.00773	0.927	0.17	0.865	32.2
Hexacosane	Oiled	D2	0.00323	0.00103	4.85E-01	6.58E+00	0.00325	0.0162	1	3.94	0.485	5.64
Hexacosane	Oiled	E2	0.00718	0.00203	0.565	9.09	0.0129	0.0153	0.739	0.375	0.578	8.23
Hexacosane	Oiled	F2	0.00468	0.00107	0.691	15.6	0.00469	0.011	1	1.66	0.691	13.4
Hexacosane	Oiled	G2	0.00798	0.00257	0.114	0.899	0.0972	0.159	0.559	0.0964	0.461	5.12
Hexacosane	Oiled	H2	0.0108	0.00191	0.845	38.3	0.0127	0.0076	0.925	0.239	0.848	33.4
Hexacosane	Oiled	I2	0.0135	0.00318	0.69	15.5	0.0177	0.0107	0.902	0.189	0.697	13.8
Hexacosane	Oiled	J2	0.00835	0.00164	0.749	17.9	0.00906	0.0091	0.956	0.504	0.75	15
Hexacosane	Oiled	AVERAGE	0.00680396			18.9769	0.01105956		0.8059971			16.839
Hexacosane	Oiled	Std Dev	0.00352284				0.00862666		0.17324844			
Hexacosane	Ammonium Nit	A3	0.00666	0.00105	0.802	28.4	0.00671	0.00705	1	0.649	0.802	24.3
Hexacosane	Ammonium Nit	B3	0.00526	0.00113	0.605	9.17	0.0126	0.0138	0.617	0.285	0.639	8.86
Hexacosane	Ammonium Nit	C3	0.0063	0.000908	0.808	29.5	0.00631	0.00651	1	0.655	0.808	25.3
Hexacosane	Ammonium Nit	D3	0.00552	0.00141	5.75E-01	9.46E+00	0.00552	0.0119	1	1.44	0.575	8.11
Hexacosane	Ammonium Nit	E3	0.00658	0.00136	0.73	19	0.0066	0.00927	1	0.875	0.73	16.3
Hexacosane	Ammonium Nit	F3	0.00646	0.00189	0.542	8.28	0.0125	0.0163	0.703	0.402	0.559	7.6
Hexacosane	Ammonium Nit	G3	0.0117	0.0022	0.762	19.2	0.0258	0.0128	0.767	0.096	0.85	28.3
Hexacosane	Ammonium Nit	H3	0.00845	0.00235	0.575	9.47	0.0154	0.0153	0.756	0.283	0.593	8.76
Hexacosane	Ammonium Nit	I3	0.0185	0.000935	0.991	634	0.0207	0.002	0.963	0.0265	0.993	710
Hexacosane	Ammonium Nit	J3	0.00615	0.00125	0.646	12.8	0.0166	0.0127	0.614	0.169	0.707	14.4
Hexacosane	Ammonium Nit	AVERAGE	0.00831745			77.928	0.01448269		0.86785979			85.193
Hexacosane	Ammonium Nit	Std Dev	0.00434766				0.00682207		0.13492702			
Hexacosane	Meister 70	A4	0.00704	0.0019	0.902	36.7	0.00723	0.00805	1	0.654	0.901	27.3
Hexacosane	Meister 70	B4	0.00786	0.00164	0.725	18.5	0.00891	0.00933	0.931	0.523	0.726	15.9
Hexacosane	Meister 70	C4	0.00568	0.00136	0.487	6.64	0.00757	0.00118	0.836	0.761	0.489	5.73
Hexacosane	Meister 70	D4	0.00664	0.00124	7.79E-01	2.47E+01	0.00673	0.00838	0.991	0.763	0.779	21.2
Hexacosane	Meister 70	E4	0.00664	0.00105	0.809	29.6	0.01	0.00791	0.792	0.314	0.816	26.6

			1st Order				RECAL					
			kinetic k				kinetic k'		fraction degradable			
Compound	Treatment	Plot	a	SE	r^2	F	a	SE	b	SE	r^2	F
Hexacosane	Meister 70	F4	0.00662	0.00147	0.716	17.6	0.00719	0.0101	0.949	0.801	0.716	15.1
Hexacosane	Meister 70	G4	0.00854	0.00141	0.854	41	0.00855	0.00695	0.999	0.446	0.854	35.1
Hexacosane	Meister 70	H4	0.00784	0.00171	0.666	14	0.0184	0.0131	0.682	0.163	0.728	16.1
Hexacosane	Meister 70	I4	0.0109	0.00183	0.788	22.3	0.0243	0.0113	0.759	0.0873	0.859	30.5
Hexacosane	Meister 70	J4	0.00966	0.00244	0.676	14.6	0.0177	0.0137	0.764	0.205	0.715	15.1
Hexacosane	Meister 70	AVERAGE	0.00753163			22.564	0.00948566		0.80259791			20.863
Hexacosane	Meister 70	Std Dev	0.00143504				0.00445172		0.10264569			
Octacosane	Oiled	A2	0.0103	0.0028	0.729	18.8	0.0103	0.011	1	0.525	0.729	16.1
Octacosane	Oiled	B2	0.00293	0.000747	0.609	10.9	0.00293	0.0132	1	3.63	0.609	9.33
Octacosane	Oiled	C2	0.0112	0.000403	0.992	773	0.0111	0.00153	1	0.0633	0.992	640
Octacosane	Oiled	D2	0.00289	0.0011	3.99E-01	4.64E+00	0.00291	0.0197	1	5.48	0.399	3.98
Octacosane	Oiled	E2	0.00692	0.00218	0.509	7.27	0.0137	0.0179	0.705	0.378	0.528	6.7
Octacosane	Oiled	F2	0.00419	0.00113	0.61	11	0.00422	0.0131	1	2.28	0.61	9.4
Octacosane	Oiled	G2	0.00848	0.00268	0.153	1.26	0.0797	0.102	0.58	5.46	0.476	5.46
Octacosane	Oiled	H2	0.00992	0.00215	0.77	23.4	0.0134	0.0101	0.862	0.269	0.778	21
Octacosane	Oiled	I2	0.014	0.00333	0.706	16.8	0.0176	0.0105	0.916	0.19	0.712	14.8
Octacosane	Oiled	J2	0.00925	0.0018	0.75	18	0.0136	0.0102	0.835	0.252	0.762	16
Octacosane	Oiled	AVERAGE	0.00763449			88.507	0.01131227		0.92822963			74.277
Octacosane	Oiled	Std Dev	0.00370007				0.00698843		0.09363955			
Octacosane	Ammonium Nit	A3	0.00622	0.00105	0.78	24.8	0.00627	0.00764	1	0.776	0.78	21.2
Octacosane	Ammonium Nit	B3	0.00407	0.00111	0.446	4.83	0.0137	0.02	0.501	0.291	0.494	4.88
Octacosane	Ammonium Nit	C3	0.00546	0.000789	0.818	31.4	0.0055	0.00672	1	0.82	0.818	26.9
Octacosane	Ammonium Nit	D3	0.00502	0.00146	5.14E-01	7.39E+00	0.00643	0.0144	0.848	1.2	0.514	6.35
Octacosane	Ammonium Nit	E3	0.00582	0.0014	0.654	13.2	0.00583	0.011	1	1.24	0.654	11.3
Octacosane	Ammonium Nit	F3	0.00598	0.00198	0.476	6.36	0.0129	0.0194	0.66	0.425	0.496	5.92
Octacosane	Ammonium Nit	G3	0.012	0.00221	0.777	20.9	0.0256	0.0123	0.776	0.0883	0.858	30.2
Octacosane	Ammonium Nit	H3	0.00952	0.00264	0.573	9.38	0.0192	0.0164	0.749	0.209	0.606	9.21
Octacosane	Ammonium Nit	I3	0.0194	0.00186	0.966	170	0.0271	0.0037	0.907	0.0279	0.986	365
Octacosane	Ammonium Nit	J3	0.0055	0.00142	0.523	7.67	0.018	0.0179	0.558	0.189	0.597	8.9

			1st Order				RECAL					
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Compound	Treatment	Plot	a	SE	r^2	F	a	SE	b	SE	r^2	F
Octacosane	Ammonium Nit	AVERAGE	0.00710972			29.593	0.01539343		0.82061472			48.986
Octacosane	Ammonium Nit	Std Dev	0.00399715				0.00925911		0.13356562			
Octacosane	Meister 70	A4	0.00744	0.000892	0.948	72.7	0.00658	0.0067	1	0.626	0.933	42
Octacosane	Meister 70	B4	0.00699	0.00159	0.689	15.5	0.0087	0.0107	0.879	0.586	0.691	13.4
Octacosane	Meister 70	C4	0.00527	0.00162	0.353	3.82	0.00702	0.0153	0.831	1.1	0.354	3.29
Octacosane	Meister 70	D4	0.00598	0.00125	7.41E-01	2.00E+01	0.00598	0.00953	1	1.04	0.741	17.2
Octacosane	Meister 70	E4	0.00602	0.00112	0.759	22	0.00855	0.00928	0.809	0.481	0.763	19.3
Octacosane	Meister 70	F4	0.00578	0.00138	0.684	15.1	0.00578	0.011	1	1.25	0.684	13
Octacosane	Meister 70	G4	0.00806	0.00152	0.816	31.1	0.00808	0.00807	1	0.564	0.816	26.7
Octacosane	Meister 70	H4	0.00723	0.00189	0.585	9.88	0.0171	0.0161	0.667	0.221	0.634	10.4
Octacosane	Meister 70	I4	0.0128	0.00179	0.876	42.2	0.0228	0.00763	0.821	0.0724	0.921	58.7
Octacosane	Meister 70	J4	0.00828	0.00255	0.582	9.76	0.0157	0.0172	0.736	0.304	0.612	9.47
Octacosane	Meister 70	AVERAGE	0.007203			24.206	0.01042926		0.82180485			21.346
Octacosane	Meister 70	Std Dev	0.00189086				0.00576444		0.09792679			
Triacontane	Oiled	A2	0.0086	0.00214	0.726	18.6	0.00874	0.0105	0.991	0.647	0.726	15.9
Triacontane	Oiled	B2	0.00243	0.000599	0.553	8.68	0.00788	0.0152	0.432	0.475	0.569	7.92
Triacontane	Oiled	C2	0.0111	0.0002	0.998	2890	0.0111	0.000765	1	0.0318	0.998	2400
Triacontane	Oiled	D2	0.00269	0.00113	2.78E-01	2.69E+00	0.0027	0.0219	1	6.66	0.278	2.31
Triacontane	Oiled	E2	0.00563	0.00188	0.389	4.45	0.0173	0.0234	0.574	0.272	0.433	4.58
Triacontane	Oiled	F2	0.00316	0.00107	0.466	6.12	0.00316	0.0173	1	4.35	0.466	5.24
Triacontane	Oiled	G2	0.0077	0.0027	0.00545	0.0383	0.0876	0.143	0.543	0.105	0.402	4.04
Triacontane	Oiled	H2	0.00997	0.00173	0.8	28	0.0184	0.00877	0.768	0.124	0.85	34
Triacontane	Oiled	I2	0.0136	0.00364	0.6	10.5	0.0221	0.0145	0.842	0.165	0.625	9.99
Triacontane	Oiled	J2	0.00743	0.00185	0.578	8.22	0.0153	0.0159	0.71	0.268	0.608	7.76
Triacontane	Oiled	AVERAGE	0.00784504			297.72983	0.01183687		0.83408693			249.174
Triacontane	Oiled	Std Dev	0.0037785				0.00590737		0.1900534			
Triacontane	Ammonium Nit	A3	0.00638	0.00115	0.683	15.1	0.00893	0.00886	0.822	0.437	0.687	13.2
Triacontane	Ammonium Nit	B3	0.00279	0.000976	0.309	2.69	0.0127	0.0172	0.388	0.35	0.344	2.62
Triacontane	Ammonium Nit	C3	0.00476	0.00092	0.661	13.7	0.00476	0.00925	1	1.37	0.661	11.7

			1st Order				RECAL					
			kinetic k				kinetic k'		fraction degradable			
Compound	Treatment	Plot	a	SE	r^2	F	a	SE	b	SE	r^2	F
Triacontane	Ammonium Nit	D3	0.00509	0.00144	3.95E-01	4.57E+00	0.0229	0.0254	0.502	0.162	0.448	4.87
Triacontane	Ammonium Nit	E3	0.00534	0.00111	0.672	14.3	0.00561	0.0098	0.966	1.12	0.672	12.3
Triacontane	Ammonium Nit	F3	0.00555	0.00165	0.479	6.44	0.0148	0.0189	0.598	0.296	0.518	6.45
Triacontane	Ammonium Nit	G3	0.0116	0.0023	0.729	16.1	0.0285	0.0151	0.751	0.0857	0.838	25.8
Triacontane	Ammonium Nit	H3	0.00993	0.00241	0.629	11.9	0.0216	0.015	0.739	0.155	0.681	12.8
Triacontane	Ammonium Nit	I3	0.0173	0.00159	0.963	154	0.0262	0.0026	0.883	0.0203	0.993	685
Triacontane	Ammonium Nit	J3	0.00517	0.00122	0.475	6.33	0.023	0.0187	0.507	0.12	0.629	10.2
Triacontane	Ammonium Nit	AVERAGE	0.00662647			24.513	0.01833771		0.7709581			78.494
Triacontane	Ammonium Nit	Std Dev	0.00385937				0.00887506		0.15653328			
Triacontane	Meister 70	A4	0.00759	0.000759	0.958	91.6	0.00762	0.00473	1	0.355	0.958	68.7
Triacontane	Meister 70	B4	0.00659	0.00137	0.66	13.6	0.0127	0.0114	0.705	0.271	0.685	13.1
Triacontane	Meister 70	C4	0.00471	0.00187	0.129	1.04	0.0769	0.194	0.401	0.136	0.172	1.25
Triacontane	Meister 70	D4	0.00595	0.000821	8.39E-01	3.64E+01	0.00849	0.00682	0.805	0.356	0.844	32.5
Triacontane	Meister 70	E4	0.00549	0.00102	0.721	18.1	0.0106	0.0101	0.682	0.313	0.736	16.8
Triacontane	Meister 70	F4	0.00576	0.00106	0.752	21.2	0.00799	0.00917	0.816	0.533	0.755	18.5
Triacontane	Meister 70	G4	0.00825	0.00101	0.894	59.2	0.00917	0.00541	0.943	0.293	0.895	51
Triacontane	Meister 70	H4	0.00733	0.00167	0.574	9.43	0.0229	0.016	0.622	0.126	0.692	13.5
Triacontane	Meister 70	I4	0.012	0.00179	0.839	31.3	0.0255	0.00898	0.779	0.0654	0.915	54.1
Triacontane	Meister 70	J4	0.00897	0.00193	0.646	12.8	0.024	0.013	0.678	0.104	0.789	22.5
Triacontane	Meister 70	AVERAGE	0.00706837			29.467	0.01288062		0.70563459			29.195
Triacontane	Meister 70	Std Dev	0.00175922				0.00793918		0.15065312			
Dotriacontane	Oiled	A2	0.00871	0.00237	0.691	15.7	0.00924	0.0117	0.967	0.643	0.692	13.5
Dotriacontane	Oiled	B2	0.0019	0.000608	0.364	4	0.0172	0.0287	0.252	0.147	0.41	4.17
Dotriacontane	Oiled	C2	0.0113	0.000286	0.996	1.49E+03	0.0113	0.00107	1	0.0127	0.996	1240
Dotriacontane	Oiled	D2	0.00253	0.000986	2.65E-01	2.53E+00	0.0148	0.0311	0.336	0.276	0.281	2.35
Dotriacontane	Oiled	E2	0.006	0.00193	0.347	3.72	0.0229	0.0264	0.556	0.186	0.448	4.86
Dotriacontane	Oiled	F2	0.00272	0.000984	0.387	4.41	0.00272	0.0189	1	5.69	0.387	3.78
Dotriacontane	Oiled	G2	No fit				0.1	0.185	0.542	0.102	0.41	4.16
Dotriacontane	Oiled	H2	0.00933	0.0019	0.686	15.3	0.0224	0.0116	0.7	0.107	0.807	25.1

			1st Order				RECAL					
			kinetic k				kinetic k'		fraction degradable			
Compound	Treatment	Plot	a	SE	r^2	F	a	SE	b	SE	r^2	F
Dotriacontane	Oiled	I2	0.0121	0.00328	0.593	10.2	0.0168	0.0129	0.873	0.24	0.603	9.12
Dotriacontane	Oiled	J2	0.00614	0.00186	0.419	4.33	0.0183	0.0238	0.6	0.246	0.48	4.61
Dotriacontane	Oiled	AVERAGE	0.00703016			172.243333	0.01294458		0.84325906			131.165
Dotriacontane	Oiled	Std Dev	0.00409833				0.00682808		0.2386479			
Dotriacontane	Ammonium Nit	A3	0.00531	0.00142	0.521	7.6	0.00532	0.0125	1	1.6	0.521	6.52
Dotriacontane	Ammonium Nit	B3	0.00151	0.000856	0.0968	0.643	0.0191	0.0638	0.206	0.211	0.147	0.859
Dotriacontane	Ammonium Nit	C3	0.00376	0.000922	0.567	9.17	0.00377	0.0122	1	2.46	0.567	7.86
Dotriacontane	Ammonium Nit	D3	0.00387	0.00141	1.60E-01	1.34E+00	0.0407	0.0644	0.383	0.126	0.282	2.35
Dotriacontane	Ammonium Nit	E3	0.00367	0.00092	0.531	7.94	0.00367	0.0126	1	2.61	0.531	6.8
Dotriacontane	Ammonium Nit	F3	0.00476	0.0015	0.398	4.64	0.0168	0.0226	0.519	0.249	0.457	5.04
Dotriacontane	Ammonium Nit	G3	0.00999	0.00225	0.629	10.2	0.0286	0.0201	0.706	0.106	0.748	14.9
Dotriacontane	Ammonium Nit	H3	0.00951	0.00252	0.505	7.15	0.0297	0.0217	0.676	0.123	0.625	10
Dotriacontane	Ammonium Nit	I3	0.0165	0.00143	0.964	162	0.0249	0.0222	0.88	0.0191	0.994	834
Dotriacontane	Ammonium Nit	J3	0.00368	0.00109	0.186	1.6	0.0311	0.0317	0.388	0.0955	0.507	6.18
Dotriacontane	Ammonium Nit	AVERAGE	0.00540971			21.2283	0.01552483		0.7087203			89.4509
Dotriacontane	Ammonium Nit	Std Dev	0.00407361				0.01198769		0.22363572			
Dotriacontane	Meister 70	A4	0.00535	0.00105	0.85	22.6	0.0054	0.00991	1	1.23	0.849	16.9
Dotriacontane	Meister 70	B4	0.00487	0.00117	0.552	8.63	0.0125	0.0145	0.585	0.297	0.59	8.63
Dotriacontane	Meister 70	C4	0.00338	0.00194	0.0344	0.249	0.00548	0.0311	0.704	2.68	0.0347	0.216
Dotriacontane	Meister 70	D4	0.0045	0.000707	7.75E-01	2.42E+01	0.00809	0.00839	0.684	0.401	0.786	22
Dotriacontane	Meister 70	E4	0.00388	0.00797	0.685	15.2	0.00516	0.0106	0.814	1.15	0.686	13.1
Dotriacontane	Meister 70	F4	0.00426	0.00106	0.611	11	0.00612	0.0128	0.778	1.05	0.613	9.49
Dotriacontane	Meister 70	G4	0.00703	0.000939	0.861	43.3	0.00757	0.00601	0.956	0.442	0.861	37.1
Dotriacontane	Meister 70	H4	0.00649	0.00148	0.511	7.31	0.0253	0.0177	0.57	0.109	0.674	12.4
Dotriacontane	Meister 70	I4	0.0111	0.00189	0.774	20.6	0.0272	0.0114	0.743	0.0695	0.89	40.3
Dotriacontane	Meister 70	J4	0.00732	0.00166	0.518	7.51	0.0268	0.0153	0.599	0.091	0.761	19.1
Dotriacontane	Meister 70	AVERAGE	0.00573392			16.0599	0.01188859		0.67563751			17.9236
Dotriacontane	Meister 70	Std Dev	0.001882				0.00848077		0.10975889			
Tetratriacontane	Oiled	A2	0.0961	0.0161	0.981	354	0.1	0.0259	0.918	0.0143	0.975	235

			1st Order				RECAL					
			kinetic k				kinetic k'		fraction degradable			
Compound	Treatment	Plot	a	SE	r^2	F	a	SE	b	SE	r^2	F
Tetratriacontane	Oiled	B2	0.00198	0.000721	0.145	1.19	0.0199	0.0348	0.254	0.142	0.242	1.91
Tetratriacontane	Oiled	C2	0.00583	0.0012	0.371	3.53	0.0754	0.124	0.482	0.044	0.822	23.1
Tetratriacontane	Oiled	D2	0.00178	0.000739	1.46E-01	1.19E+00	0.0352	0.0771	0.203	0.101	0.166	1.19
Tetratriacontane	Oiled	E2	0.00382	0.00792	0.33	3.44	0.0298	0.0191	0.396	0.0629	0.673	12.4
Tetratriacontane	Oiled	F2	0.00134	0.000644	0.173	1.46	0.00134	0.0269	1	18.1	0.173	1.25
Tetratriacontane	Oiled	G2	no fit				0.0545	0.128	0.279	0.115	0.0179	0.109
Tetratriacontane	Oiled	H2	0.00354	0.000774	0.156	1.29	0.0387	0.0225	0.366	0.0154	0.726	15.9
Tetratriacontane	Oiled	I2	0.00294	0.000986	0.251	2.35	0.00347	0.0176	0.876	3.45	0.251	2.02
Tetratriacontane	Oiled	J2	no fit				0.0721	0.35	0.363	0.108	0.302	2.16
Tetratriacontane	Oiled	AVERAGE	0.0034249			46.05625	0.033316		0.55145462			29.5039
Tetratriacontane	Oiled	Std Dev	0.00850968				0.03160688		0.26774799			
Tetratriacontane	Ammonium Nit	A3	no fit	no fit	no fit	no fit	no fit	no fit	no fit	no fit	no fit	no fit
Tetratriacontane	Ammonium Nit	B3	no fit	no fit	no fit	no fit	no fit	no fit	no fit	no fit	no fit	no fit
Tetratriacontane	Ammonium Nit	C3	0.0023	0.000739	0.334	3.51	0.00231	0.0171	1	6.23	0.334	3
Tetratriacontane	Ammonium Nit	D3	no fit	no fit	no fit	no fit	no fit	no fit	no fit	no fit	no fit	no fit
Tetratriacontane	Ammonium Nit	E3	0.0022	0.000678	0.255	2.4	0.0108	0.0218	0.338	0.0326	0.265	2.16
Tetratriacontane	Ammonium Nit	F3	0.00218	0.000769	0.203	1.78	0.0212	0.0352	0.271	0.138	0.289	2.44
Tetratriacontane	Ammonium Nit	G3	0.00481	0.00124	0.228	1.77	0.0535	0.0863	0.45	0.0756	0.59	7.18
Tetratriacontane	Ammonium Nit	H3	no fit	no fit	no fit	no fit	0.0945	0.26	0.363	0.109	0.235	1.85
Tetratriacontane	Ammonium Nit	I3	0.00519	0.00108	0.289	2.44	0.0802	0.137	0.449	0.037	0.85	28.3
Tetratriacontane	Ammonium Nit	J3	no fit				0.0234	0.0884	0.175	0.19	0.0907	0.598
Tetratriacontane	Ammonium Nit	AVERAGE	0.00305016			2.38	0.01838234		0.37544268			6.504
Tetratriacontane	Ammonium Nit	Std Dev	0.00127647				0.02226927		0.08157131			
Tetratriacontane	Meister 70	A4	no fit	no fit	no fit	no fit	no fit	no fit	no fit	no fit	no fit	no fit
Tetratriacontane	Meister 70	B4	0.000563	0.000655	0.0854	0.654	0.00384	0.0733	0.184	2.65	0.0867	0.57
Tetratriacontane	Meister 70	C4	no fit	no fit	no fit	no fit	no fit	no fit	no fit	no fit	no fit	no fit
Tetratriacontane	Meister 70	D4	0.00268	0.00045	5.88E-01	9.99E+00	0.0127	0.0112	0.373	0.142	0.661	11.7
Tetratriacontane	Meister 70	E4	0.00165	0.000255	0.719	17.9	0.00166	0.00855	0.991	4.5	0.719	15.3
Tetratriacontane	Meister 70	F4	0.00126	0.000713	0.27	2.59	0.00126	0.0318	1	23	0.27	2.22
Tetratriacontane	Meister 70	G4	0.00419	0.000398	0.879	50.9	0.00649	0.00493	0.742	0.353	0.883	45.2

			1st Order				RECAL					
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Compound	Treatment	Plot	a	SE	r^2	F	a	SE	b	SE	r^2	F
Tetratriacontane	Meister 70	H4	0.00347	0.00077	0.266	2.53	0.0349	0.0259	0.362	0.0609	0.614	9.55
Tetratriacontane	Meister 70	I4	0.00405	0.000729	0.581	8.32	0.0166	0.0144	0.468	0.139	0.653	9.4
Tetratriacontane	Meister 70	J4	no fit	no fit	no fit	no fit	0.0386	0.0362	0.283	0.0569	0.545	7.18
Tetratriacontane	Meister 70	AVERAGE	0.00250017			13.2691429	0.01068587		0.37415469			12.64
Tetratriacontane	Meister 70	Std Dev	0.00125584				0.01037455		0.1172103			
Hexatriacontane	Oiled	A2	0.0892	0.0145	0.98	342	0.1	0.0177	0.999	0.018	0.987	461
Hexatriacontane	Oiled	B2	No fit				0.1	0.299	0.252	0.077	0.141	0.986
Hexatriacontane	Oiled	C2	0.00682	0.000624	0.909	59.7	0.0127	0.00455	0.724	0.109	0.939	76.8
Hexatriacontane	Oiled	D2	No fit				0.1	0.27	0.238	0.0656	0.231	1.8
Hexatriacontane	Oiled	E2	0.00376	0.00103	0.219	1.96	0.0296	0.0312	0.391	0.103	0.414	4.25
Hexatriacontane	Oiled	F2	No fit				0.1	0.315	0.22	0.0706	0.173	1.25
Hexatriacontane	Oiled	G2	No fit				No fit					
Hexatriacontane	Oiled	H2	No fit				0.072	0.0721	0.426	0.0611	0.567	7.85
Hexatriacontane	Oiled	I2	0.00665	0.00294	0.0212	0.151	0.0695	0.153	0.499	0.162	0.146	1.02
Hexatriacontane	Oiled	J2	0.00176	0.00111	0.138	0.959	0.0108	0.0491	0.283	0.604	0.154	0.909
Hexatriacontane	Oiled	AVERAGE	0.00632923			80.954	0.03363192		0.61318073			61.7627778
Hexatriacontane	Oiled	Std Dev	0.01133853				0.03459899		0.3339269			
Hexatriacontane	Ammonium Nit	A3	0.00324	0.00172	0.119	0.946	0.00324	0.027	1	6.56	0.119	0.811
Hexatriacontane	Ammonium Nit	B3	No fit				No fit					
Hexatriacontane	Ammonium Nit	C3	0.00203	0.00111	0.128	1.03	0.00203	0.0295	1	12.5	0.128	0.879
Hexatriacontane	Ammonium Nit	D3	No fit				No fit					
Hexatriacontane	Ammonium Nit	E3	No fit				No fit					
Hexatriacontane	Ammonium Nit	F3	0.00168	0.000891	0.0179	0.128	0.0345	0.0902	0.202	0.121	0.0932	0.617
Hexatriacontane	Ammonium Nit	G3	0.00479	0.00135	0.228	1.77	0.0399	0.056	0.457	0.0977	0.516	5.33
Hexatriacontane	Ammonium Nit	H3	No fit				0.0671	0.0793	0.419	0.0751	0.469	5.3
Hexatriacontane	Ammonium Nit	I3	0.00691	0.000946	0.736	16.7	0.0274	0.00547	0.591	0.0262	0.972	175
Hexatriacontane	Ammonium Nit	J3	No fit				0.1	0.423	0.153	0.0661	0.121	0.827
Hexatriacontane	Ammonium Nit	AVERAGE	0.0037367			4.1148	0.02477754		0.43389592			26.9662857
Hexatriacontane	Ammonium Nit	Std Dev	0.00207644				0.01609119		0.17664595			

			1st Order				RECAL					
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Compound	Treatment	Plot	a	SE	r^2	F	a	SE	b	SE	r^2	F
Hexatriacontane	Meister 70	A4	0.0027	0.00264	0.0752	0.325	0.0203	0.106	0.34	0.519	0.129	0.444
Hexatriacontane	Meister 70	B4	No fit				0.0881	0.359	0.21	0.101	0.0948	0.628
Hexatriacontane	Meister 70	C4	No fit				No fit					
Hexatriacontane	Meister 70	D4	No fit				0.0834	0.184	0.241	0.0666	0.237	1.87
Hexatriacontane	Meister 70	E4	0.00114	0.000344	0.452	5.78	0.00114	0.0171	1	13.8	0.452	4.96
Hexatriacontane	Meister 70	F4	0.00199	0.000705	0.251	2.35	0.0117	0.0257	0.301	0.302	0.281	2.35
Hexatriacontane	Meister 70	G4	0.00412	0.000624	0.615	11.2	0.0153	0.01	0.484	0.121	0.693	13.6
Hexatriacontane	Meister 70	H4	No fit				0.1	0.121	0.363	0.0446	0.633	10.3
Hexatriacontane	Meister 70	I4	0.00474	0.00091	0.56	7.64	0.0206	0.0162	0.494	0.111	0.7	11.7
Hexatriacontane	Meister 70	J4	No fit				0.1	0.159	0.315	0.0512	0.509	6.22
Hexatriacontane	Meister 70	AVERAGE	0.00256165			5.459	0.01945953		0.33720473			5.78577778
Hexatriacontane	Meister 70	Std Dev	0.00144449				0.02295703		0.09214334			
Sum of Alkanes	Oiled	A2	0.0107	0.00148	0.866	45.3	0.0164	0.00643	0.827	0.118	0.892	49.6
Sum of Alkanes	Oiled	B2	0.00295	0.000571	0.706	16.8	0.00295	0.01	0.999	2.73	0.706	14.4
Sum of Alkanes	Oiled	C2	0.00778	0.000547	0.962	150	0.00786	0.00321	1	0.232	0.961	124
Sum of Alkanes	Oiled	D2	0.00206	0.000842	0.357	3.89	0.00208	0.0219	1	9.05	0.357	3.33
Sum of Alkanes	Oiled	E2	0.00527	0.00164	0.45	5.72	0.0131	0.0185	0.627	0.376	0.475	5.43
Sum of Alkanes	Oiled	F2	0.0029	0.001	0.494	6.82	0.00293	0.0178	0.999	4.9	0.493	5.85
Sum of Alkanes	Oiled	G2	no fit		no fit		0.1	0.269	0.408	0.112	0.25	2
Sum of Alkanes	Oiled	H2	0.00671	0.00127	0.757	21.8	0.00994	0.0094	0.8	0.381	0.764	19.4
Sum of Alkanes	Oiled	I2	0.00899	0.00212	0.585	9.87	0.00893	0.00986	1	0.591	0.585	8.46
Sum of Alkanes	Oiled	J2	0.00632	0.00159	0.575	8.13	0.009	0.0133	0.814	0.634	0.579	6.87
Sum of Alkanes	Oiled	AVERAGE	0.00544461			29.8144444	0.00918475		0.72331878			23.924
Sum of Alkanes	Oiled	Std Dev	0.00274366				0.00693733		0.22330435			
Sum of Alkanes	Ammonium Nit	A3	0.0049	0.00106	0.66	13.6	0.00494	0.0102	1	1.45	0.66	11.6
Sum of Alkanes	Ammonium Nit	B3	0.00411	0.00686	0.709	14.6	0.0091	0.0101	0.604	0.351	0.727	13.3
Sum of Alkanes	Ammonium Nit	C3	0.00519	0.00086	0.751	21.1	0.00524	0.00778	1	1.015	0.751	18.1
Sum of Alkanes	Ammonium Nit	D3	0.00536	0.00139	0.531	7.92	0.00876	0.0136	0.742	0.626	0.534	6.88
Sum of Alkanes	Ammonium Nit	E3	0.00543	0.00114	0.71	17.1	0.00544	0.00976	1	1.21	0.71	14.7

			1st Order				RECAL					
			kinetic k				kinetic k'		fraction degradable			
Compound	Treatment	Plot	a	SE	r^2	F	a	SE	b	SE	r^2	F
Sum of Alkanes	Ammonium Nit	F3	0.00495	0.00116	0.636	12.2	0.00719	0.012	0.784	0.784	0.638	10.6
Sum of Alkanes	Ammonium Nit	G3	0.00656	0.00144	0.543	7.13	0.025	0.0215	0.584	0.123	0.65	9.28
Sum of Alkanes	Ammonium Nit	H3	0.00509	0.00156	0.438	5.46	0.0104	0.0173	0.657	0.54	0.446	4.83
Sum of Alkanes	Ammonium Nit	I3	0.0139	0.0014	0.939	92.8	0.022	0.00444	0.856	0.0468	0.969	158
Sum of Alkanes	Ammonium Nit	J3	0.00444	0.000725	0.679	14.8	0.0171	0.0105	0.492	0.107	0.78	21.3
Sum of Alkanes	Ammonium Nit	AVERAGE	0.00589877			20.671	0.01208988		0.72080637			26.859
Sum of Alkanes	Ammonium Nit	Std Dev	0.002541				0.00715585		0.16170681			
Sum of Alkanes	Meister 70	A4	0.00481	0.000963	0.843	21.5	0.0049	0.0103	1	1.46	0.843	16.1
Sum of Alkanes	Meister 70	B4	0.00642	0.00128	0.716	17.6	0.00726	0.00927	0.926	0.705	0.716	15.1
Sum of Alkanes	Meister 70	C4	0.00446	0.0015	0.302	3.04	0.0033	0.0208	1	4.94	0.232	1.81
Sum of Alkanes	Meister 70	D4	0.00592	0.00092	0.829	34	0.00593	0.00713	0.999	0.782	0.829	29.1
Sum of Alkanes	Meister 70	E4	0.00489	0.000726	0.795	27.1	0.00803	0.00776	0.729	0.4	0.801	24.1
Sum of Alkanes	Meister 70	F4	0.00594	0.000898	0.81	29.9	0.0033	0.0162	1	3.84	0.477	5.46
Sum of Alkanes	Meister 70	G4	0.00627	0.00122	0.796	27.3	0.00628	0.00881	1	0.892	0.796	23.4
Sum of Alkanes	Meister 70	H4	0.00597	0.00121	0.695	15.9	0.012	0.0113	0.68	0.285	0.716	15.1
Sum of Alkanes	Meister 70	I4	0.00693	0.00141	0.597	8.88	0.022	0.0177	0.62	0.125	0.656	9.55
Sum of Alkanes	Meister 70	J4	0.00767	0.0017	0.622	11.5	0.0218	0.0141	0.642	0.125	0.744	17.4
Sum of Alkanes	Meister 70	AVERAGE	0.00580256			19.672	0.00881582		0.71045052			15.712
Sum of Alkanes	Meister 70	Std Dev	0.00087272				0.00570663		0.13194817			

Appendix H Hypothetical Scenario of Bioremediation Management Following a Coastal Oil Spill

This is a hypothetical scenario of a coastal oil spill which makes landfall. In this scenario a decision is made to consider using nutrient application to speed biodegradation of the oil. With the exception of the names of the Louisiana regulatory bodies, the names used to keep persons or corporations in the scenario distinct from each other are fictitious.

Spill and Landfall

The Melvin Glippe Oil Company (Glippe) pipeline carrying sweet Louisiana crude oil ruptured on or about August 30, 2001. Prior to the discovery and shutdown of the pipeline, approximately 5000 bbl of crude oil were released. Approximately 80 percent of the oil was captured, dispersed, or evaporated in open water, however, 20 percent (1000 bbls) found its way into the marsh before it could be intercepted. Based on aerial reconnaissance it has impacted approximately 28 acres of marsh in the Oaken Dog Wildlife Management Area (Oaken Dog) in a parish of coastal Louisiana. The impacted area is approximately 150 feet wide on either side of a shallow water body, Ugly Jack Bay, and extends about 4000 feet along the axis of the bay. Lateral spread was limited due to the slopes of natural levees of former distributaries adjoining Ugly Jack Bay. The impacted area is a salt marsh with *S. alterniflora* vegetation. No rookeries have been spotted in the impacted area.

The Louisiana Department of Wildlife and Fisheries (LDWLF) owns and manages Oaken Dog. Portions of Oaken Dog adjacent to the spill landfall are used primarily for duck hunting and fishing. LDWLF has indicated it is willing to share decision making with the Louisiana Department of Environmental Quality (LDEQ). The Coast Guard has indicated its satisfaction with the open water

cleanup and that it is willing to let the LDEQ act as lead agency in managing the cleanup of the marsh. LDWLF posts the area to hunters and fishermen pending the LDEQ notifying it that the risk from the oil has been eliminated. No local citizens or other likely stakeholders have indicated any interest in the situation; the nearest resident is over 2 miles away.

Kay Modeaux, Glippe's Executive Vice President in Charge of Environmental Restoration, Public Relations, and Endangered Reptiles has executed a contract with Jupiter Doak Environmental Associates Division of DSB Services (Doak) to provide environmental consulting services relating to the landfall of the spill.

Early Monitoring of Biodegradation

Initial sampling by Doak under contract to Glippe indicates TPH concentrations of 19,000 mg/kg. Jean-Luke Malchus, chief engineer at Doak, who was appointed project manager early in the project, has heard of the RECAP standards (LDEQ, 1998). He reviews them thoroughly and determines that for crude oil the remedial standards are based on concentrations of various PAHs and of the gasoline fraction, diesel fraction, and oil fractions of TPH (TPH-G, TPH-D, and TPH-O). Malchus obtains another sample and has it analyzed for these fractions of TPH. Malchus prepares Table H.1 showing the screening level (10^{-6} excess cancer risk, Hazard Index=0.1) and the Management Option 1 (MO-1) levels (10^{-6} excess cancer risk, Hazard Index=1.0). Despite management option 1 not being strictly applicable to the site since over one-half acre is impacted, he intends to use it as a reasonable cleanup standard to begin negotiations with the LDEQ on behalf of Glippe. Malchus is also familiar with research into oil spills done at L.S.U., and in particular with Tim Tate's dissertation. Malchus notes the similarity between Tate's site and the spill area,

Table H.1 Possible Target Cleanup Goals

Compound	Screening Level mg/kg	MO-1 Level mg/kg	Maximum Site Concentration mg/kg
PAHs			
Acenaphthlene	400	4000	12
Benzo(a)pyrene	0.33	0.33	BDL
Chrysene	61	61	BDL
Dibenzo(a,h)anthracene	0.33	0.33	BDL
Indeno(1,2,3-cd)pyrene	0.61	0.61	BDL
Benzo(k)fluoranthene	6.1	6.1	BDL
Benzo(a)anthracene	0.61	0.61	BDL
Fluoranthene	260	2600	BDL
Fluorene	280	2800	BDL
Naphthalene	210	2100	28
Pyrene	220	2200	BDL
TPH Fractions			
TPH-G (C6-C12)	130	1300	1500
TPH-D (C10-C20)	130	1300	15000
TPH-O (C20-C28)	180	1800	3000

namely that the oil is sweet Louisiana crude and the marsh is about half *Spartina alterniflora* with the rest being *Juncus Roemerianus*. He calculates that the 1000 bbls over 28 acres is approximately 1.16 kg of oil per square meter assuming a specific gravity of 0.82.

Malchus uses the information from Tate's dissertation to estimate the likely time for natural biodegradation to achieve the remedial standards. Since in the salt marsh the degradation rates are quite similar for the various alkanes, he suspects that the rates of the various fractions of TPH will also be similar. Since the TPH-D fraction will require a greater degree of degradation to reach the MO-1 level, it appears that TPH-D values will drive the cleanup. It also appears that the PAH values in the sweet Louisiana crude will not be problematic since they are much less than the MO-1 level. Malchus reasons that the straight chain alkanes would degrade at rates as experienced in Tate's research. The branched alkanes would likely degrade slower, but some oil would dissipate due to dissolution or other abiotic processes. Assuming that the slowing effects of the branched chains was offset by the speeding effects of physical oil loss, Malchus elects to use Tate's value of 0.0054/day as a first order rate in modeling decay of the oil. He prepares Figure H.1 to represent his conceptual model of the fate of the oil. Based on Figure H.1 the 1300 mg/kg MO-1 level would be reached in about 450 days.

Malchus and Modeaux discuss the timing of natural biodegradation and like it. Modeaux instructs Malchus to prepare a letter to LDEQ on Glippe's letterhead proposing attempted cleanup to the MO-1 level of 1300 mg/kg for TPH-D, with no further action prior to sampling at 450 days. The letter is prepared and sent to LDEQ.

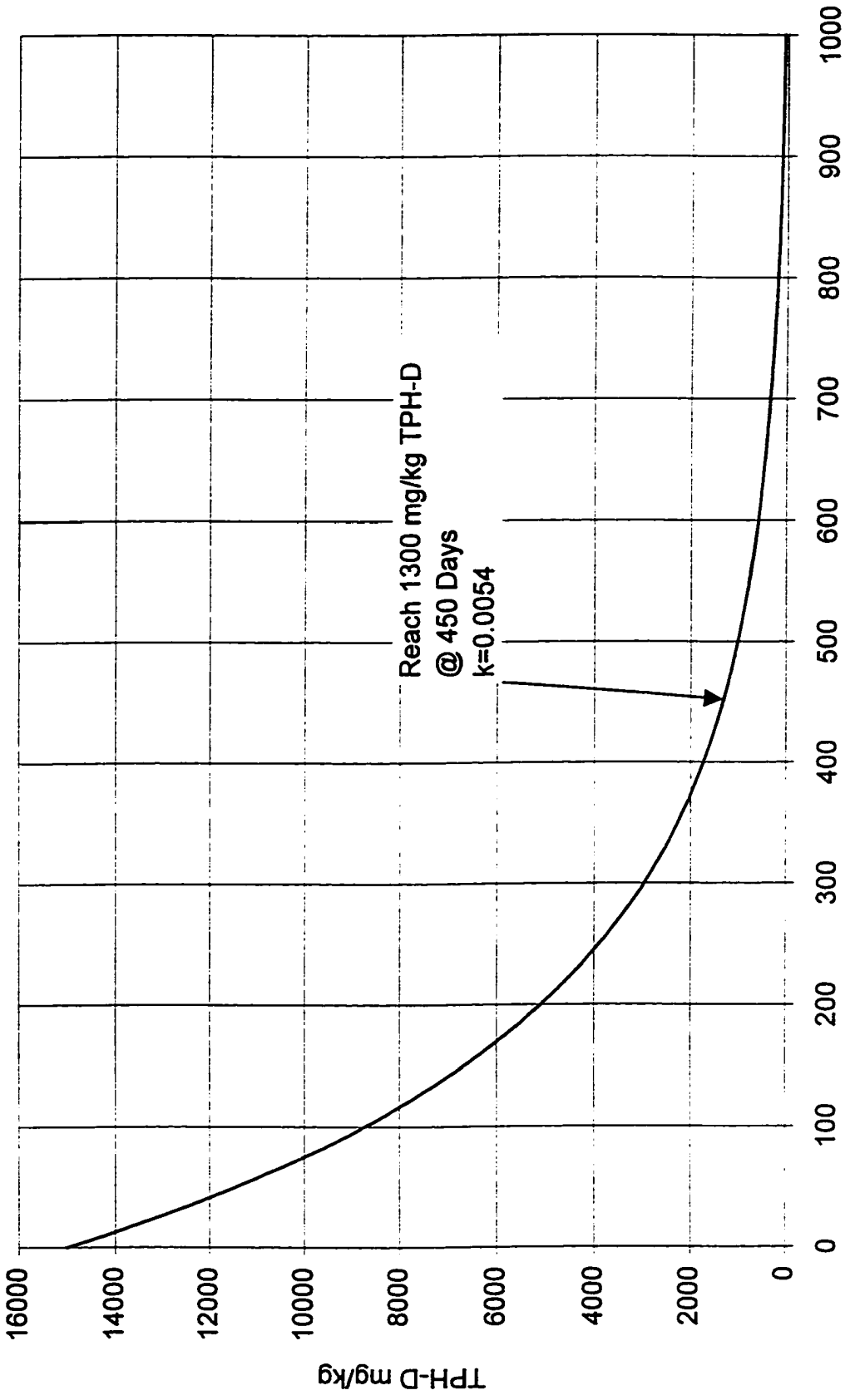


Figure H.1 Originally Anticipated Rate of TPH-D Decay

LDEQ agrees to try natural degradation for the site. LDEQ does not agree with no further action prior to sampling at 450 days. LDEQ requests a work plan with details and a schedule of periodic monitoring to demonstrate that degradation is occurring at the rate anticipated. LDEQ also requires a limited ecological risk assessment, since surface water has been impacted and the spill covers over 1 acre. Kay Modeaux issues a contract to Professor Augustus Northland of Texas A&M to conduct the ecological risk assessment.

Agreement is reached that Doak will sample on behalf of Glippe at four random locations at 30, 60, 90, and 120 days after the baseline sampling, analyze for TPH-G,D, and O, and monitor nitrogen (both nitrate and ammonia) in the porewater. After the results of the fourth monthly sampling LDEQ will decide if biodegradation is proceeding satisfactorily. LDEQ emphasizes its interest in the bioremediation working and not being perceived as a non-action.

Meanwhile Harold Glippe, First Principal Chief Senior Vice President of Glippe has established a relationship with the Civil Engineering Department at L.S.U. (his alma mater) and arranged to have the mass of the alkane components determined on GC/MS, and the degradation rates determined and compared to Tate's research. Professor Ivan L. Pange has agreed to assign his post-doc Martin Van Buren to the task.

Doak samples the site four more times. This together with its initial sampling has allowed determination of a trend in the biodegradation. Average TPH-D concentrations have fallen from 15,000 mg/kg to 11,700 mg/kg and all four samples are relatively close in value. Doak has information from L.S.U. for alkanes at the site. Based on first order kinetics, the k is 0.0029/day for the sum of dodecane through n-dotriacontane and k is 0.0031/day for TPH-D. At this rate the remedial standard of 1300 mg/kg TPH-D will not be reached until day 790.

This is shown of Figure H.2. Doak has also checked porewater and found average porewater to have 0.8 mg/l nitrate as N and 2 mg/l ammonia as N. Doak has concluded that the degradation rate and the amount of nitrogen in the porewater are significantly less than in Tate's dissertation data. He does not know why, but suspects that lack of nitrogen may be limiting the progress of the oil degradation.

Doak has been slow to invoice Glippe, not having anticipated the degree of effort the LDEQ would require for a "no-action" alternative. Doak finally submits his first invoice for the project to Glippe. Due to the size of the invoice and the long period it covers, Doak provides extensive detail to assist Glippe in approving it. The invoice is attached as Table H.2.

Doak advises Glippe that decay of the oil is not proceeding as fast as anticipated. He suggests they scope out a pilot program before the LDEQ does it for them. A budget for the pilot test, as shown on Table H.3 is prepared.

Meanwhile a local duck hunter and attorney, Happy Rocque, has asked to examine the case files several times at the LDEQ. The raw data has been reported to LDEQ after each sampling event but the LDEQ project manager, Issac "Billy Bob" Chicot laughs, saying he is stumped as to why degradation is not going faster.

About this time Professor Northland completes his ecological risk assessment which Glippe submits to LDEQ. The assessment concludes that the oil components provide minimal threat to non-human receptors, and that no critical habitat has been impacted, however, attempts to remove oil from the marsh would likely damage the habitat value of the marsh. LDEQ places the document in the files and continues to manage the situation based on human

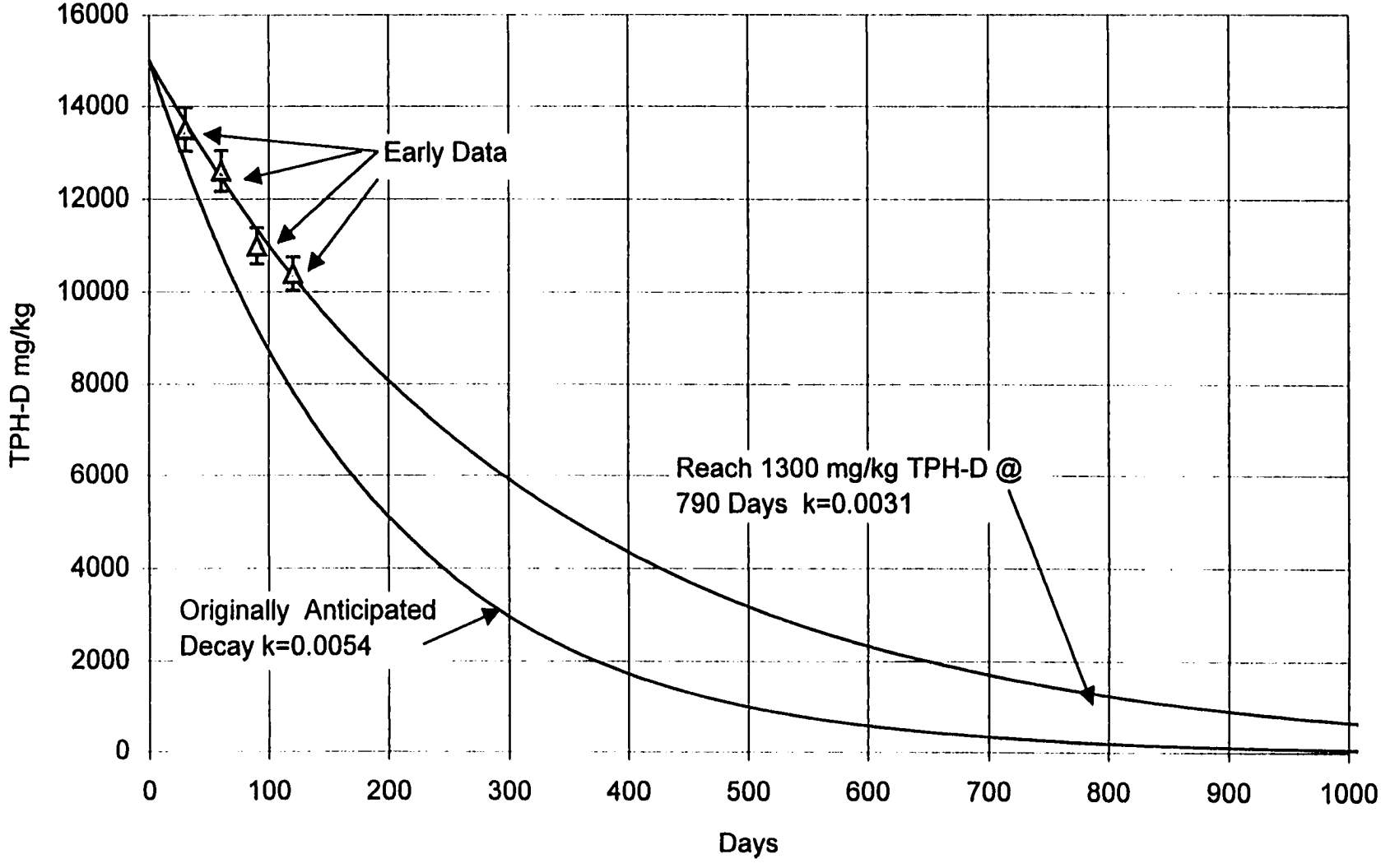


Figure H.2 Actual Early Progress of TPH-D Decay

Table H.2 Doak's Invoice to Glippe

Jupiter Doak Environmental Associates, Inc.
"Balancing the Environment and Your Profitability"

Invoice for Services Rendered from Project Beginning (Pipeline Rupture) through Present (Decision for Pilot Test)

Item	Unit of Measure	Unit Cost	Number of Units	Extension	Subtotals
Marsh Testings					
Soil sampling 5 events	manhours	$55	96	$5,280	
Travel	trips	$150	5	$750	
TPH analyses	each	$220	20	$4,400	
GC/MS alkane analyses by LSU	lump		20	$10,000	
Nitrate	each	$15	20	$300	
Ammonia	each	$25	20	$500	
					$21,230
Data Interpretation and Reports					
Sr. Engineer	manhours	$95	60	$5,700	
Jr. Envr Scientist	manhours	$55	160	$8,800	
					$14,500
Meetings and Negotiations					
Sr. Engineer	manhours	$95	24	$2,280	
					$2,280
Shop supplies					$200
Total					$38,210

Note: A contract has been set up with LSU to set up GC/MS procedures and run samples for alkanes from C12 to C36 plus pristane and phytane. The contract provides for running up to 100 samples and interpretation of kinetic parameters. Additional samples wi

Amounts overdue in excess of 30 days subject to 3% per month interest.

Table H.3 Estimated Cost of Pilot Test

Item	Unit of Measure	Unit Cost	Number of Units	Extension	Subtotals
Preparation of Work Plan					
Sr Engineer	manhour	$95	16	$1,520	
Jr Engineer	manhour	$55	40	$2,200	
					$3,720
Establishment of Field Plots					
Jr Engineer	manhour	$55	24	$1,320	
Travel	trip	$150	1	$150	
Material and fertilizer	lump	$200	1	$200	
					$1,670
Marsh Testings					
Soil sampling 5 events	man hour	$55	100	$5,500	
Travel	trips	$150	5	$750	
TPH analyses	each	$220	40	$8,800	
GC/MS alkane analyses by LSU	lump		40	$0	
Nitrate	each	$15	40	$600	
Ammonia	each	$25	40	$1,000	
					$16,650
Data Interpretation and Reports					
Sr. Engineer	manhour	$95	32	$3,040	
Jr. Envr Scientist	manhour	$55	80	$4,400	
					$7,440
Meetings and Negotiations					
Sr. Engineer	manhour	$95	12	$1,140	
					$1,140
Total					$30,620

Note: No charge for GC/MS work since still within the 100 sample limit.

health risk considerations using the cleanup levels originally proposed by Matchus based upon the RECAP document.

Glippe sends a letter Doak writes for him to the LDEQ offering to conduct a pilot nutrient addition study and also transmits the data gathered to date by L.S.U. LDEQ agrees that the pilot study seems appropriate and requests that Glippe submit a work plan for review prior to beginning the pilot study. The work plan outline as developed by Doak for Glippe follows.

Pilot Test Work Plan

Experimental Plots: Four blocks will be established in the impacted area for application of a nitrogen source. Each block will have a plot with nutrients and one without. The size of each plot will be 6 foot by 6 foot. The location of the blocks will be selected randomly. Each block will have 600 grams of ammonium nitrate applied by hand.

Monitoring: Every 2 weeks a porewater sample will be taken from each of the nutrient enriched plots and the concentration of nitrate and ammonia determined. Each month a soil sample will be taken from each of the nutrient enriched plots plus the four non-enriched sampled plots. TPH-G, TPH-D, TPH-O, and compound to hopane ratios for 18 alkanes will be determined.

Reapplication: If the nitrate level falls below 2 mg/l and the ammonia level falls below 10 mg/l then a reapplication of fertilizer will be made at the initial rate.

Evaluation: After the four monthly measurements the kinetic parameter for first order degradation will be determined for each of the non-nutrient applied plots and for the nutrient applied plots. The average and standard deviation over each of the four will be determined. At the 0.05 significance level it will be determined whether the degradation is significantly faster in the presence of the

nutrient addition. Negotiations with LDEQ at that time will take place to determine the further course of action.

Pilot Test Execution

The pilot test is executed as scoped, scheduled, and budgeted. Revised kinetic parameters are determined for the fertilized and unfertilized conditions to be 0.0070/day and 0.0031/day respectively for TPH-D, and 0.0061/day and 0.0020/day for the ratio of the sum of the alkanes to hopane. The fertilized rate is determined to be significantly faster than the unfertilized rate at the 0.05 level of significance. The rate of loss of the fertilizer is also confirmed to be about 40 days. Based on these kinetic parameters, Jean-Luke Malchus of Doak once again compares the time to meet the remedial standard if nutrients are applied or not. Figure H.3 shows the comparison of oil fate under these two conditions. If nutrients are not applied it ill take to Day 790 to reach the remedial standard, while if nutrients are applied, the remedial standard is expected to be reached about Day 520.

Doak reports the draft results to Glippe. Modeaux asks Malchus for a budget for a full scale field application of fertilizer and a comparison of Glippe's future costs if nutrients are applied versus if they are not applied. The budget is shown in Table H.4. A comparison of anticipated costs is in Table H.5. Timelines of anticipated activities if nutrients are applied or not applied are in Table H.6 and Table H.7.

Kay Modeaux of Glippe had originally stated that if they did not enhance the biodegradation, monitoring might drag on forever. Now, looking at the proposed costs for applying nutrients in Tables H.4 and H.5 and the timelines in

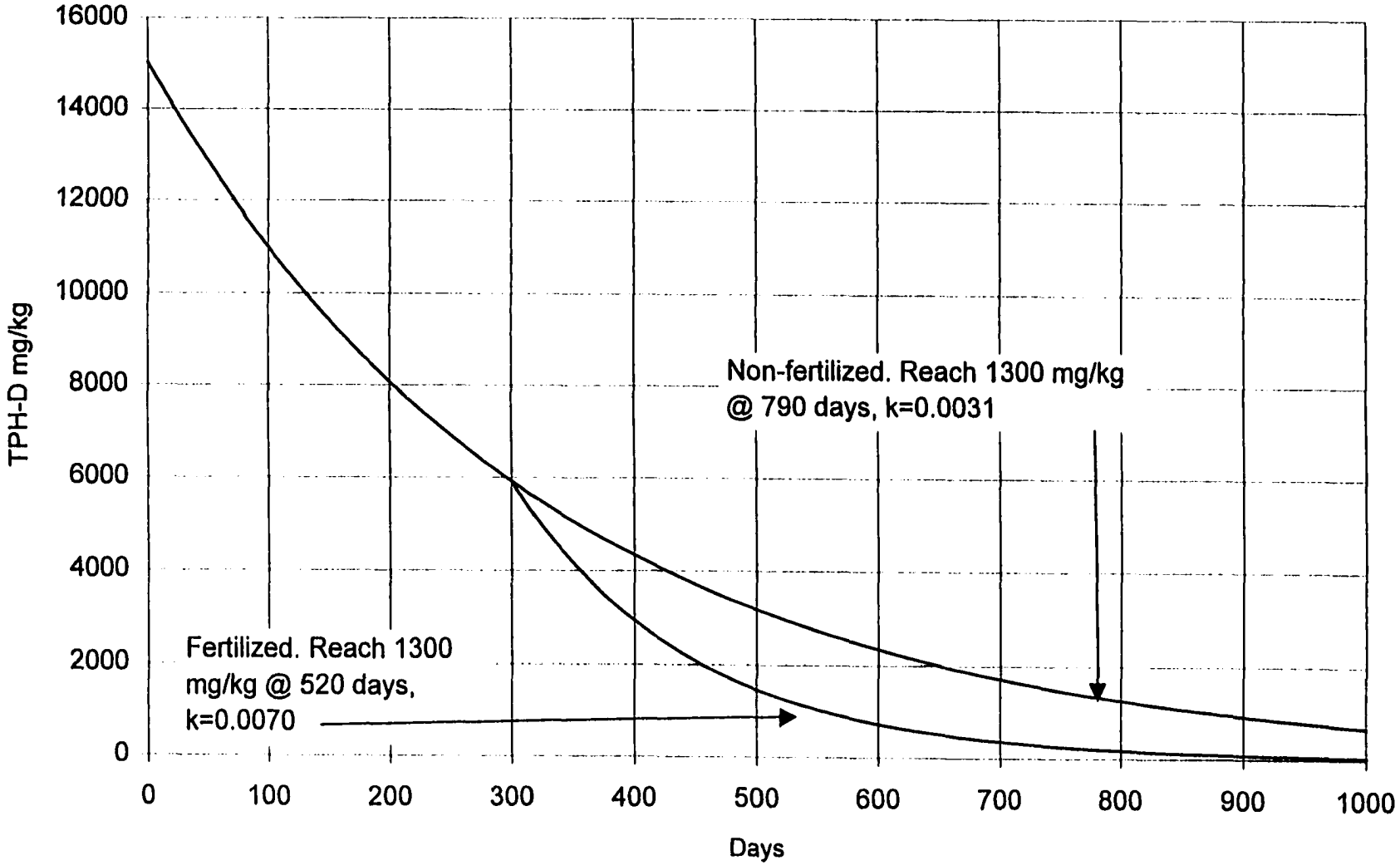


Figure H.3 Comparison of Time to Reach Remedial Standard With and Without Nutrients

Table H.4 Estimated Cost of Full Scale Application

Item	Unit of Measure	Unit Cost	Number of Units	Extension	Subtotals
Preparation of Work Plan					
Sr Engineer	manhours	$95	16	$1,520	
Jr Engineer	manhours	$55	40	$2,200	
					$3,720
Supervision of Fertilization (6 applications)					
Jr Engineer	manhours	$55	72	$3,960	
Travel	trip	$150	6	$900	
					$4,860
Nutrient Application (6 applications)					
Ammonium Nitrate	pound	$0.14	256,000	$35,840	
Crop duster	pound	$0.20	256,000	$51,200	
					$87,040
Marsh Testings					
Soil sampling w/ pore Water					
Sampling (5 events)	man hour	$55	100	$5,500	
Travel	trips	$150	5	$750	
TPH analyses	each	$220	20	$4,400	
GC/MS alkane analyses by					
LSU	lump		20	$0	
Pore Water Sampling w/o					
Soil Sampling (7 events)	man hour	$55	70	$3,850	
Travel	trips	$150	7	$1,050	
Nitrate	each	$15	48	$720	
Ammonia	each	$25	48	$1,200	
					$17,470
Data Interpretation and Reports					
Sr. Engineer	manhours	$95	60	$5,700	
Jr. Envr Scientist	manhours	$55	120	$6,600	
					$12,300
Meetings and Negotiations					
Sr. Engineer	manhours	$95	12	$1,140	
					$1,140
Total					$126,530

Table H.5 Comparison of Estimated Future Cost with and without Nutrient Application

Item	Unit of Measure	Unit Cost	Number of Units	Extension	Subtotals
Marsh Testings					
Soil sampling w/ pore Water Sampling (7 events)	manhours	$55	140	$7,700	
Travel	trips	$150	7	$1,050	
TPH analyses	each	$220	28	$6,160	
Nitrate	each	$15	28	$420	
Ammonia	each	$25	28	$700	
					$16,030
Data Interpretation and Reports					
Sr. Engineer	manhours	$95	40	$3,800	
Jr. Envr Scientist	manhours	$55	70	$3,850	
					$7,650
Meetings and Negotiations					
Sr. Engineer	manhours	$95	12	$1,140	
					$1,140
Total Cost w/o Nutrient Application					$24,820
Total w/ Nutrient Application					$126,530
Difference					$101,710

Tables H.6 and H.7, she sees that accelerating closure from Day 830 to Day 550 will cost over $100,000 with no perceived benefit. She decides against a field application of fertilizer and instructs Malchus to prepare the report not recommending it.

Closure

Malchus prepares the report on the pilot study and notes the anticipated acceleration in attaining the remedial standard. He also notes the attendant risk of eutrophication due to excess nitrogen in the marsh and quotes from past newspaper articles on the origin of the dead zones in the Gulf of Mexico. Furthermore he notes the risk of injury to the crop duster pilots applying the granular fertilizer and the possibility that the ammonium nitrate delivery could be intercepted by terrorists on the way to the airfield. He also notes the degradation of enjoyment that will be caused during overflights to apply granular fertilizer, particularly when these occur during dove season. The report recommends against nutrient application and in favor of continuation of a course of monitoring the natural degradation. The report is submitted to LDEQ.

LDEQ approves the recommendation of no nutrient application. Institutional controls continue at the site. Monitoring of the biodegradation continues and attainment of the RECAP standard is achieved. Closure is documented with a letter from LDEQ Secretary Wanda Cruz on Day 830.

Epilogue

Glippe sponsors the local science fair at the junior high school near the marsh site. Malchus, Tate, and Van Buren prepare a paper on the project which is published in a refereed journal. Issac Chicot makes a presentation at an EPA seminar on natural attenuation in Dallas. Modeaux leaves Glippe and

Table H.6 Timeline of Scenario for Full Scale Nutrient Application

Day	Event
-6	Initial Spill
-5	Landfall
0	Initial Marsh Sampling
30	Marsh sampling
60	Marsh sampling
90	Marsh sampling
120	Marsh sampling
150	Begin Pilot Test
180	Pilot test sampling
210	Pilot test sampling
240	Pilot test sampling
270	Pilot test sampling
300	Start Field Scale
300	Fertilize
300	Test Pore Water and Sample Soil
320	Test Pore Water
340	Test Pore Water and Sample Soil
345	Fertilize
360	Test Pore Water
380	Test Pore Water and Sample Soil
385	Fertilize
400	Test Pore Water
420	Test Pore Water
425	Fertilize
440	Test Pore Water and Sample Soil
460	Test Pore Water
465	Fertilize
480	Test Pore Water
500	Test Pore Water
505	Fertilize
520	Test Pore Water and Sample Soil
550	Obtain Closure

Table H.7 Timeline of Scenario if Pilot Tests But No Full Scale Application

Day	Event
-6	Initial Spill
-5	Landfall
0	Initial Marsh Sampling
30	Marsh sampling
60	Marsh sampling
90	Marsh sampling
120	Marsh sampling
150	Begin Pilot Test
180	Pilot test sampling
210	Pilot test sampling
240	Pilot test sampling
270	Pilot test sampling
300	Continue Natural Degradation
350	Test Pore Water and Sample Soil
430	Test Pore Water and Sample Soil
510	Test Pore Water and Sample Soil
590	Test Pore Water and Sample Soil
670	Test Pore Water and Sample Soil
730	Test Pore Water and Sample Soil
810	Test Pore Water and Sample Soil
830	Closure

establishes an environmental consulting firm in Klondyke, Terrebonne Parish, Louisiana where she is president and sole employee.

Appendix I Discussion of Prediction Equations

For the results of this research to become a useful engineering tool, they must result in a quantifiable conceptual model. For this reason the writer attempted to fit the data set of fraction of oil remaining versus to a number of linear and non-linear equations. The writer attempted to select those equations which had a basis in physics, chemistry, or biology of microbial degradation. The possible relevant phenomena occurring might include

- a degradation rate proportional to the amount remaining, i.e. first order decay,
- degradation at a constant rate regardless of the amount remaining, i.e. linear,
- an initial period of inactivity followed by degradation, and
- degradation which stopped short of all the oil being degraded.

To attempt to model these possible phenomena a variety of equation were tried. A summary of the more plausible ones, and their advantages and disadvantages is given in Table I.1. The curve fitting of the data to the equations was done using Table Curve 2D by Jandel Scientific. Equations tried were sorted by the F statistic, with an equation which resulted in a greater F statistic usually judged better than one generating a lesser F statistic. Usually modifying a fitting equation by adding an additional parameter resulted in a better coefficient of determination (r^2), but the F statistic identified whether the improvement in fit justified use of an additional parameter. Many of the equations used were of the same family with the simpler ones being default conditions of the more complex ones where some of the parameters were either zero or one, allowing dispensation of the use of that parameter. The confidence

Table I.1 Comparison of Equations to Predict Biodegradation

Equation Name	No. of Parameters	Expression	Advantages	Disadvantages	Predictor from Time t_1
1st Order	1	y=exp(-kt)	Traditional Prediction from any time forward k>standard error No negative y's	Cannot have non-zero asymptote	$y_2=y_1\exp(-k(t_2-t_1))$
Line 1	1	y=1+mt	Traditional Prediction from any time forward m>standard error	Negative y's possible No asymptote	$y_2=y_1+m(t_2-t_1)$
Rectangular Hyperbola, 1 parameter	1	y=1-(t/(a+t))	a>standard error No negative y's	Cannot have non-zero asymptote	None w/o knowledge of t_0 conditions
Recal	2	y=(1-b)+bexp(-k't)	No negative y's Can have non-zero asymptote	Parameter b has large standard error	None w/o knowledge of t_0 conditions
Rectangular Hyperbola, 2 parameter	2	y=1-c((t/a+t))	No negative y's Can have non-zero asymptote	Parameter c has large standaid error	None w/o knowledge of t_0 conditions

limits of parameters in the more complex equations were, therefore, examined to determine if they included the default value for using the simpler form. If so use of the complex equation was abandoned in favor of the simpler equation.

Equations tried include:

- first order decay, y=exp(-kt). This equation typically achieved the greatest F statistic. Its greatest fault is no possibility for a non-zero asymptote at time approaching infinity.
- First order decay with a lag time, y=exp(-k(t-c)). While coefficient of determination increased by adding the lag time c, F did not. The confidence interval for c was usually very wide and included c=0, which indicated that the simpler first order decay adequately modeled the data.
- First order decay with a non-zero asymptote, y=(1-b)+bexp(-k't). This version of first order decay allowed for only a fraction of the oil, b, to be biodegradable with the rest being recalcitrant. F values in some cases were nearly as good for this as for first order decay. In those cases the confidence intervals did not include b=1, which would result in this equation degenerating to the first order equation. The equation was called Recal since it allowed for a recalcitrant compound.
- A version of first order decay with both lag and a non-zero asymptote was also considered but the F statistic was low and the interval for the lag time usually was wide and included zero, thereby degenerating it to the first order with non-zero asymptote form.

- A linear equation, y=1+mt, was also tried. This equation fit well for many cases for the data taken. The weakness of this equation is that it allows negative y which is not physically possible. Since the line was constrained to a y intercept of 1, the equation was called Line1
- A one parameter rectangular hyperbola equation was also tried where the one parameter, a, was the time for the oil concentration to reach half of the initial concentration. The form of the equation is y=1-(t/(a+t)). This equation resulted in large F statistics and would not result in negative y's, but as discussed below is difficult to use for engineering purposes.
- A two parameter rectangular hyperbola equation,y=1-c((t/(a+t)), was also tried. The second parameter, c, allowed for a non-zero asymptote. The equation however, had a lower F statistic than the one parameter version and in most cases c was 1, indicating the one parameter rectangular hyperbola would do as well.

Incidentally, the name rectangular hyperbola was seen by the writer for the use of the equation in studying the relationship between haul distance and haul time in solid waste (Tchobanoglous et al, 1993), however, the form of the equation is more commonly seen in wastewater engineering as Monod kinetics.

An equation can fit the data but not be useful as a predictive tool. The decay with lag time equation closely modeled some of the data. It also predicts how much of the initial concentration is ultimately biodegradable. If one encounters a spill shortly after it happens, this equation may be useful. If however, one comes upon a spill of unknown age and degree of previous degradation, knowing the fraction of the initial oil which is degradable is of small

consolation if one does not know the initial oil concentration. Much the same can be said for the rectangular hyperbola one parameter equation. Only if one knows the time of the initial spill is it useful.

The linear equation provides data on the future concentration with no knowledge of the time of the spill or its initial concentration. Unfortunately the mathematics make no provision for slowing the degradation or preventing it from proceeding to negative values, two behaviors observed in nature.

The first order equation provides excellent information on future concentrations knowing only the concentration at the present time, since the concentration at future times is a function of the difference in the time from the present rather than an absolute time since the spill occurred. The shortcoming of the first order equation is that it does not allow for non-zero asymptotes or an increasingly slower rate parameter as likely occurs as the remaining contaminant is in voids which are poorly accessible to microbes or nutrients.

In summary, for the amount of data one is likely to have, the first order equation is most practical. As more spills are quantified, the reliability of the fraction which is biodegradable will increase and if one has good knowledge of the time of spill, the first order with non-zero asymptote form of the equation (Recal) may also become useful.

Appendix J Effect of Temperature on First Order Kinetics

Initially it was suspected that the rate parameter for the field plots was much lower than for the mesocosms due to the lower temperatures during the winter months. The mesocosms were kept in a laboratory which, while air conditioned, definitely was not overly chilly. Over the life of the mesocosms the temperature in the lab was probably in the mid to upper 70s° Fahrenheit. The field plots were established in early September and the last sampling was in early March. They were, therefore, monitored during the winter months, which even in coastal Louisiana easily could have had an average temperature 15 to 20° Fahrenheit below the mid to upper 70s experienced in the lab.

A common formula (Sawyer et al, 1994) for the temperature dependence of reaction rates is $k_2=k_1 \exp(b(t_2-t_1))$. For BOD, b has been reported to be 0.135 over 4 to 20° C, and 0.056 at 20 to 30° C (Sawyer et al, 1994). Using b of 0.12, a 10 degree C (18 degree F) difference would make a 3.3 fold difference in reaction rates. Figure 3.13 shows an apparent slowing of degradation during the middle part of the monitored period. This slowing is during fall and early winter months. The slowing also would be expected in first order decay with a constant k.

Figure J.1 shows the mean daily temperature at a nearby weather recording station over the period of the field plots. Over the last two months the average mean daily temperature is about 60° Fahrenheit. Figure J.2 depicts the degradation that would occur if the rate parameter, k, of 0.0161 at 75 degrees F varied over the experienced temperature range with b of 0.12. From Figure J.2 it can be observed that if the relationship between rate parameter and temperature held, and if both the field plots and the mesocosms had a k of 0.0161/day at 75 degrees F, then the oil in the field plots would have degraded faster than in the mesocosms for the first 100 days before finally degrading slower.

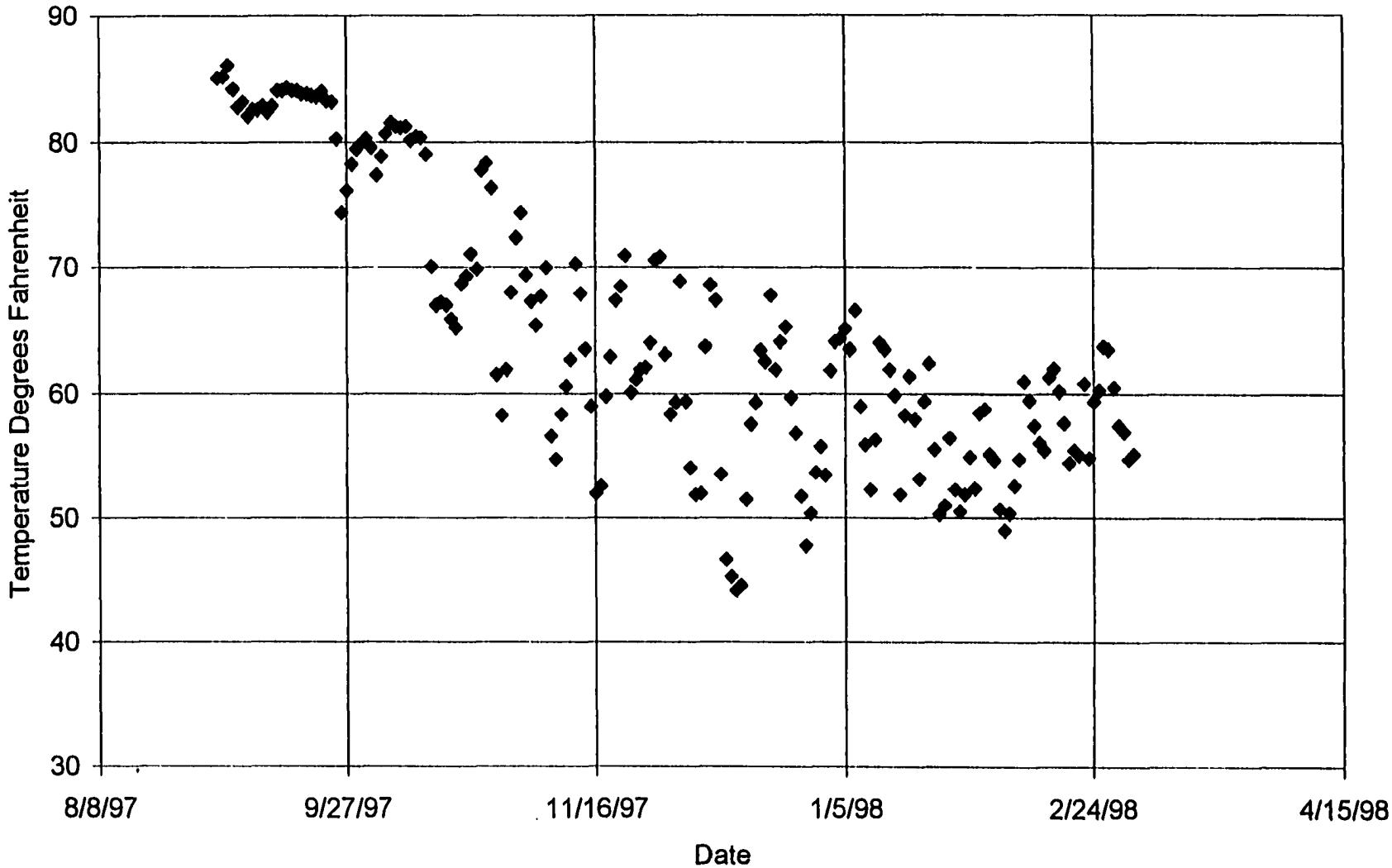


Figure J.1 Daily Mean Temperature Southwest Pass of Mississippi River

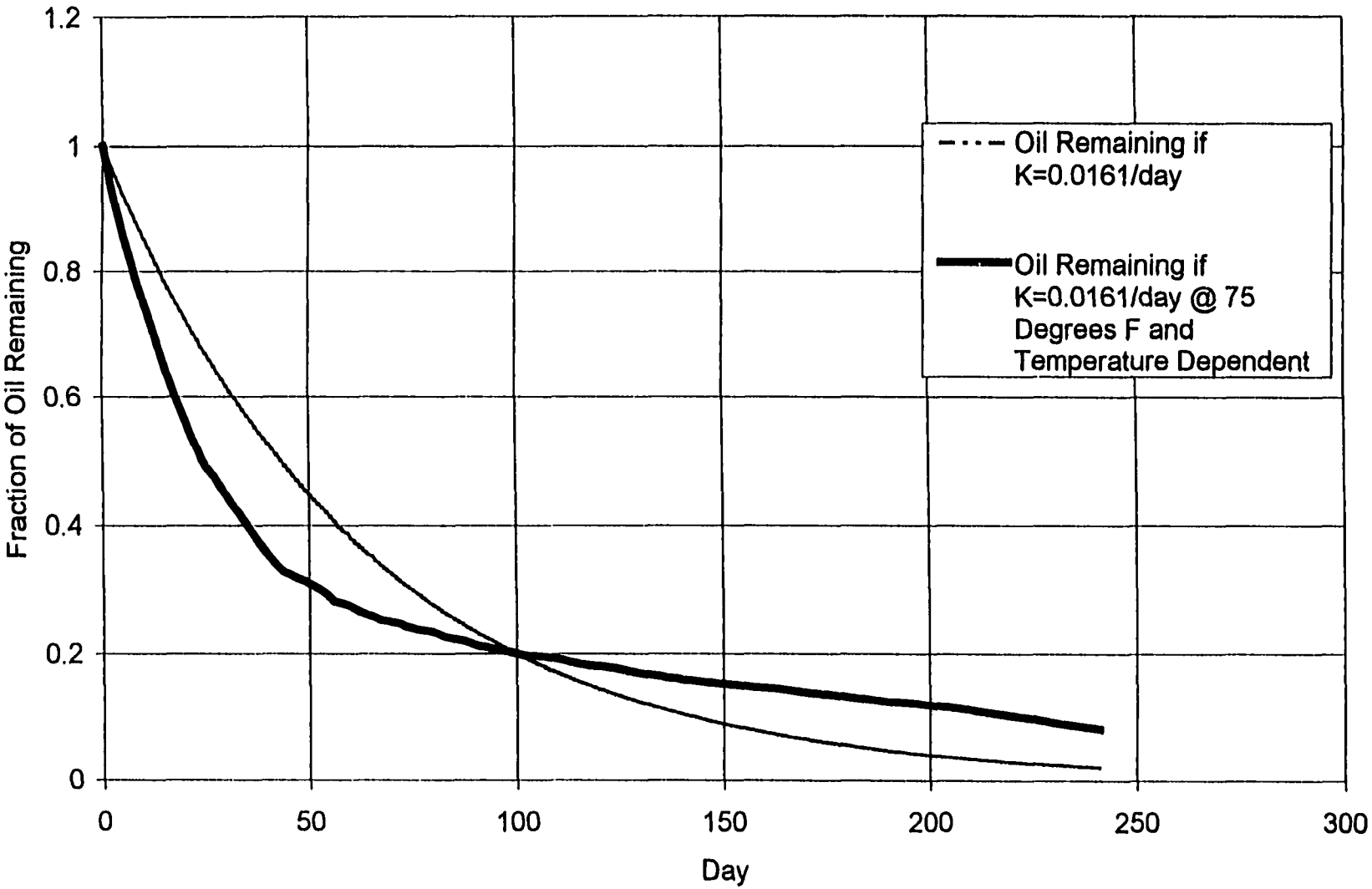
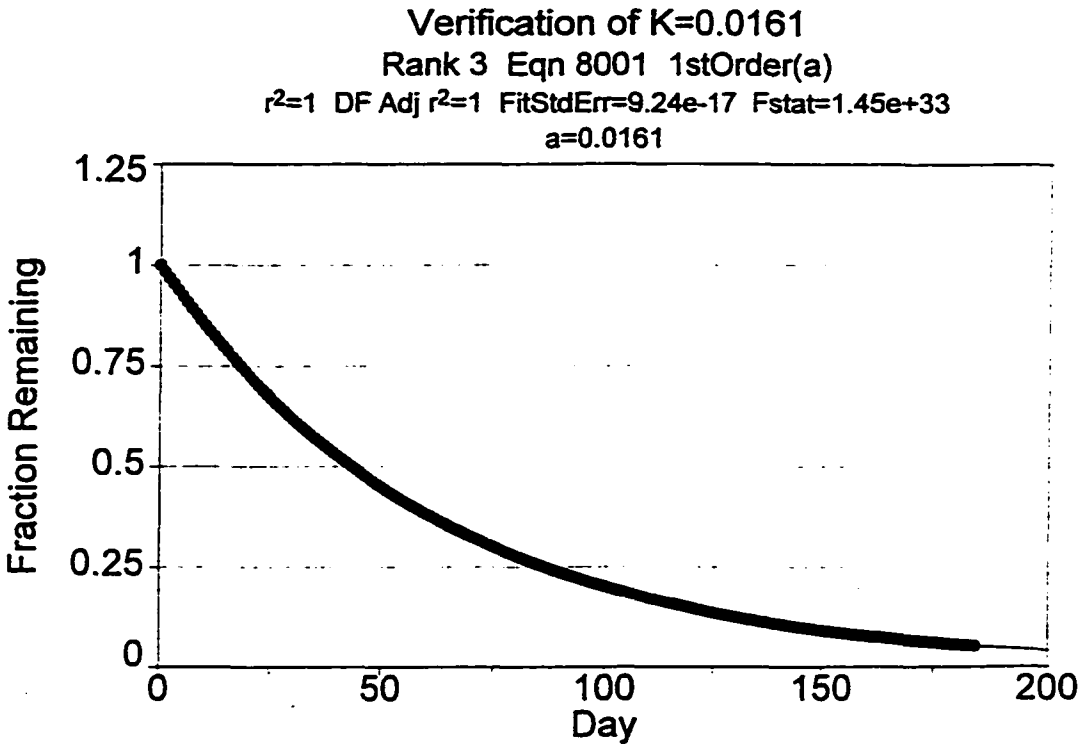


Figure J.2 Effect of Temperature on Rate of Degradation

The curves in Figure J.2 were evaluated with Table Curve 2D to determine what the equivalent reaction rate would have been over the first 181 days if the temperature dependence were true. The first Table Plot curve (Figure J.3) verifies that the generation of data with a k of 0.0161 is correctly fit by the program to this rate parameter. It can be seen that it does with a perfect goodness of fit. The second Table Plot curve (Figure J.4) establishes that the temperature dependent curve on Figure J.2 would be fit to a first order rate parameter k of 0.0195, which is greater than the mesocosm rate parameter of 0.0161. Obviously the difference of temperature between the lab and the field is not the cause of the difference in first order rate parameters.

The next two plots (Figure J.5 and J.6) are fitting of the temperature dependent rate to a recalcitrance form of the first order curve, that is, one with a non-zero asymptote [y=b exp(-at)], and to a rectangular hyperbola equation, similar to that used for Monod kinetics [y=1-(t/(a+t))]. Both of these equations fit much better than the plain first order decay curve. Remember that the temperature dependent decay curve of Figure J.2 was generated as a simple first order decay with the rate varied according the to dependency on the actual daily mean temperatures. The conclusion is that variation in temperature may cause one to conclude that a biological process either has recalcitrance or is best fit to a rectangular hyperbola type equation. In reality, if the temperature had remained constant, the data formed a perfect fit to a simple first order decay.

If the pattern of temperature variation from late summer to late spring can cause a simple first order decay phenomenon to be interpreted as recalcitrance, what would the effect of the opposite weather pattern be? Figure J.7 is the same observed mean daily temperature values but reversed in order. Figure J.8



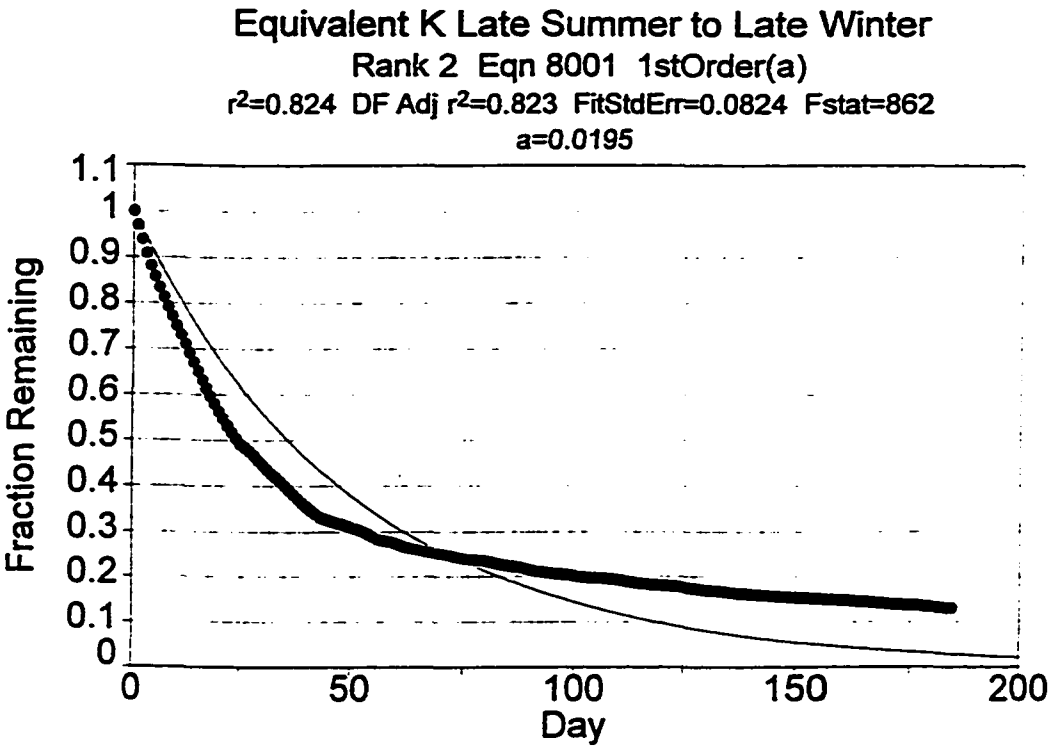
Rank 3 Eqn 8001 1stOrder(a)

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
1.0000000000	1.0000000000	9.237986e-17	1.451443e+33

Parm	Value	Std Error	t-value	90% Confidence Limits	
a	0.016100000	3.90266e-19	4.12539e+16	0.016100000	0.016100000

Date	Time	File Source
Aug 2, 1998	3:45:24 PM	c:\disser\chap3fig\tempkine.xls

Figure J.3 Verification of K=0.0161



Rank 2 Eqn 8001 1stOrder(a)

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.8241088499	0.8231476961	0.0824008938	862.10152304

Parm	Value	Std Error	t-value	90% Confidence Limits	
a	0.019452277	0.000453020	42.93915023	0.018703335	0.020201219

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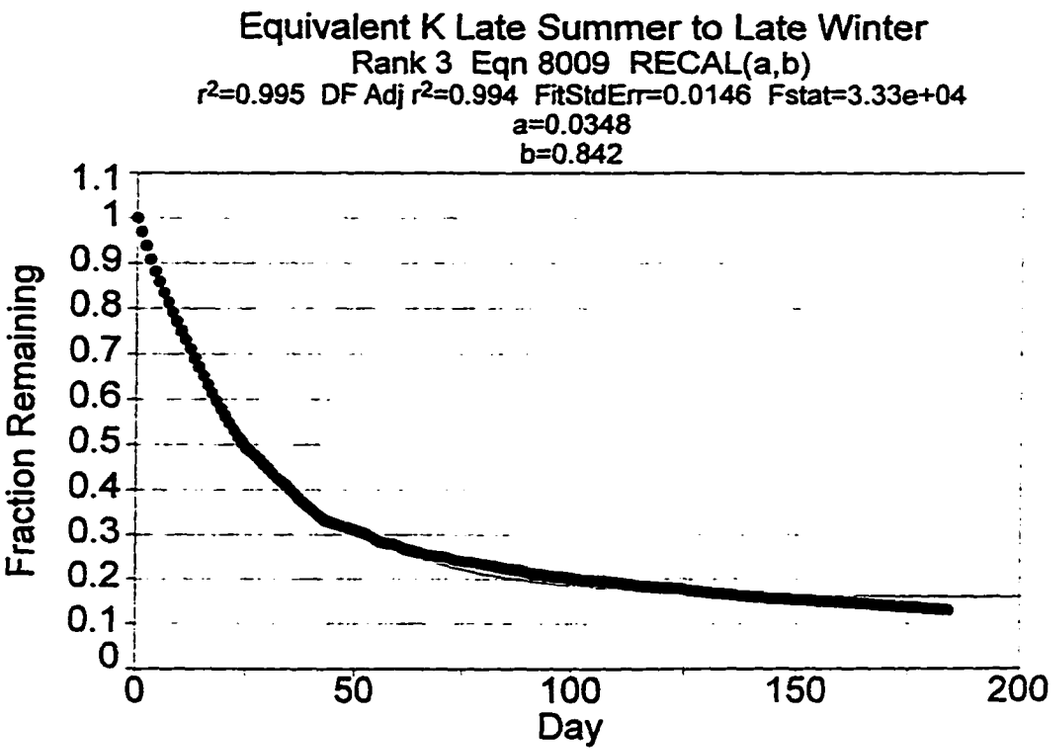
Figure J.4 Equivalent K Late Summer to Late Winter, 1st Order Fit



Rank 3 Eqn 8009 RECAL(a,b)

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9945361638	0.9944761216	0.0145627077	33309.951123

Parm	Value	Std Error	t-value	90% Confidence Limits	
a	0.034820132	0.000301139	115.6282432	0.034322267	0.035317996
b	0.841523267	0.001639083	513.4109178	0.838813416	0.844233119

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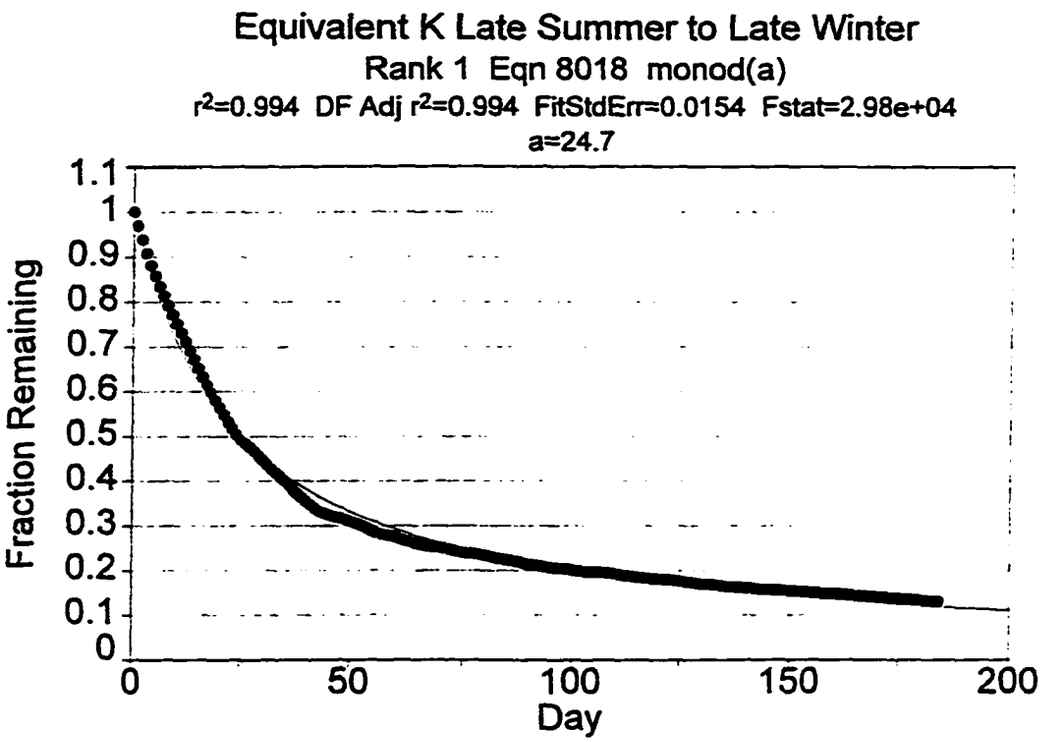
Figure J.5 Equivalent K Late Summer to Late Winter, RECAL Fit



Rank 1 Eqn 8018 *monod(a)*

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9938635856	0.9938300533	0.0153910152	29800.937253

Parm	Value	Std Error	t-value	90% Confidence Limits	
a	24.72012319	0.160053038	154.4495718	24.45552001	24.98472638

Date	Time	File Source
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Figure J.6 Equivalent K Late Summer to Late Winter, Rectangular Hyperbola Fit

presents the first order decay according to a k of 0.0161 and also based on a k dependent on the temperature variation of Figure J.7. Now rather than resulting in a more steeply decaying behavior, the effect of temperature has flattened the behavior making it appear linear. The next four plots show the generated decay behavior fit to a linear fit (Figure J.9), a rectangular hyperbola fit (Figure J.10), a first order decay (Figure J.11), and a first order decay with recalcitrance (Figure J.12). In this case what was a simple first order decay at a constant temperature is best fit to a line, only because of the temperature variation,

In conclusion, one should be very wary of assigning one of the more complex fits to a phenomenon that is expected to be first order decay since temperature dependence may mask the true relationship.

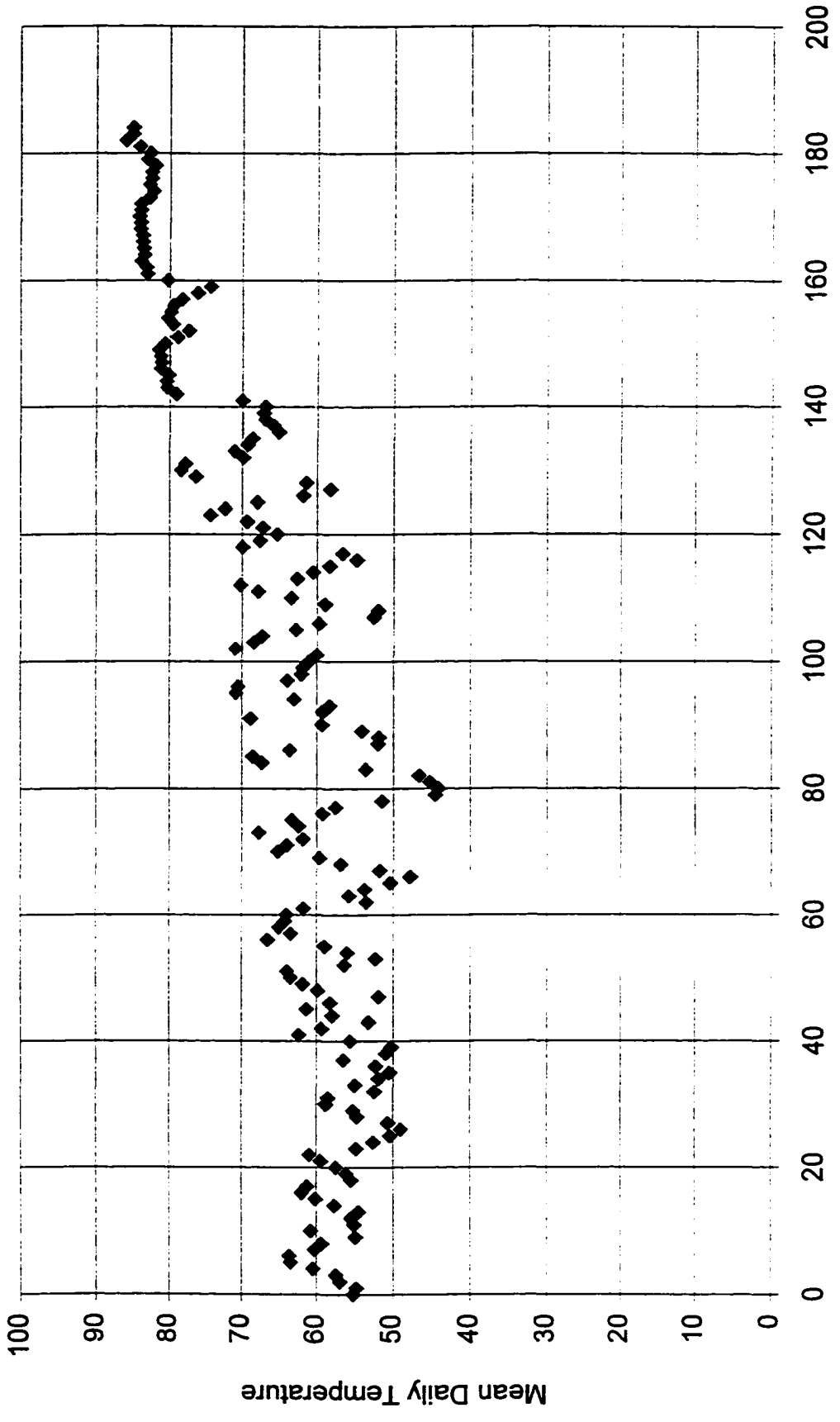


Figure J.7 Reversed Temperature Order

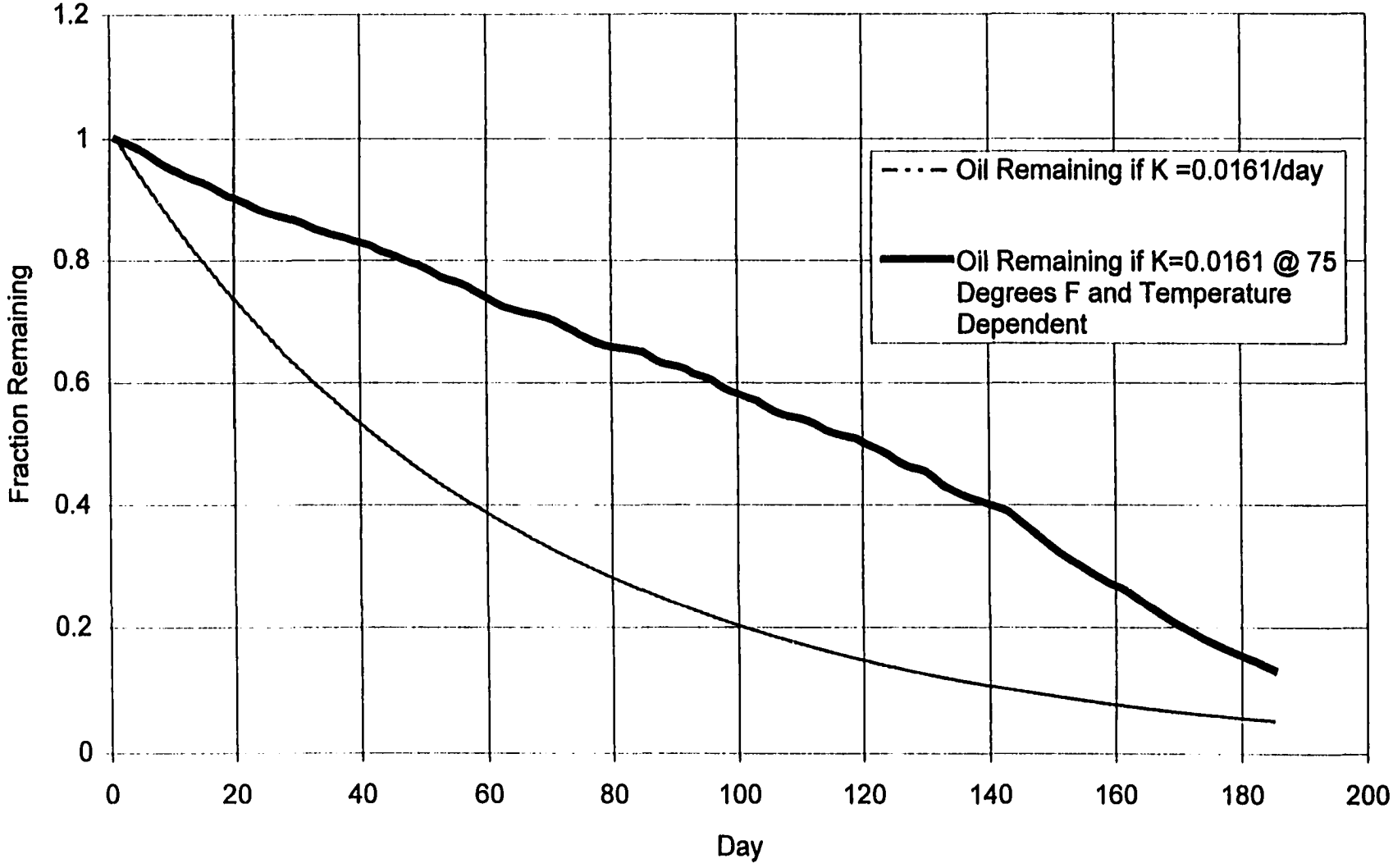
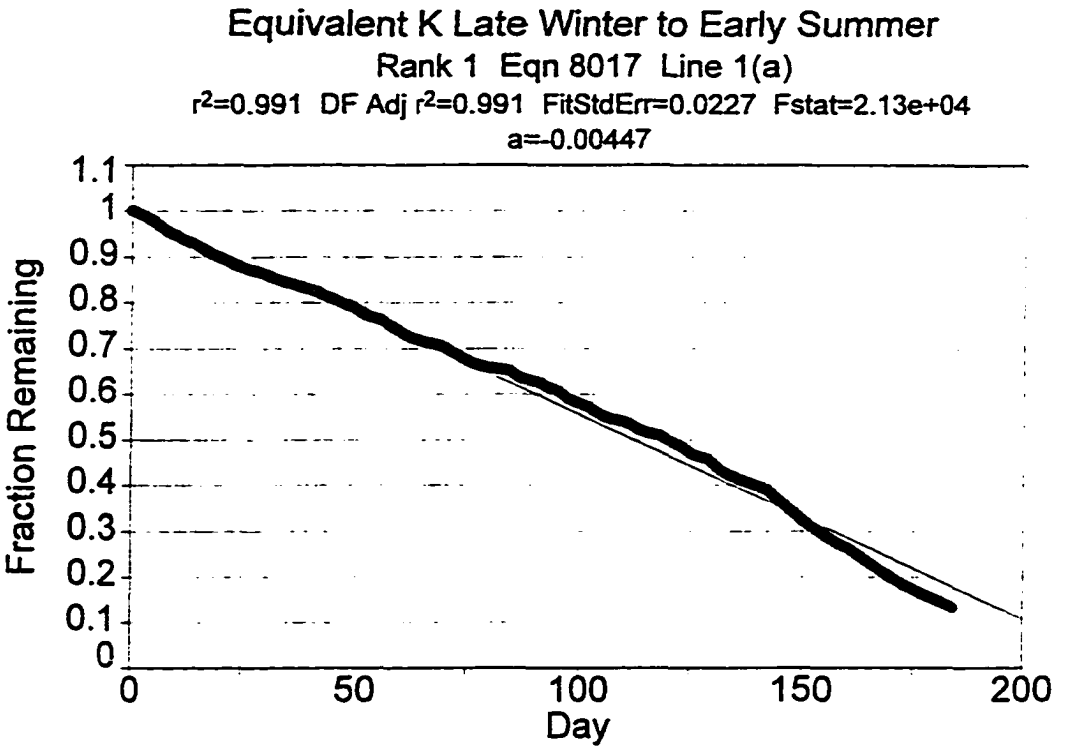


Figure J.8 Effect of Temperature on Fraction Remaining



Rank 1 Eqn 8017 Line 1(a)

r2 Coef Det	DF Adj r2	Fit Std Err	F-value
0.9914330331	0.9913862190	0.0226662295	21293.846370

Parm	Value	Std Error	t-value	90% Confidence Limits	
a	-0.00446645	1.56656e-05	-285.112195	-0.00449235	-0.00444055

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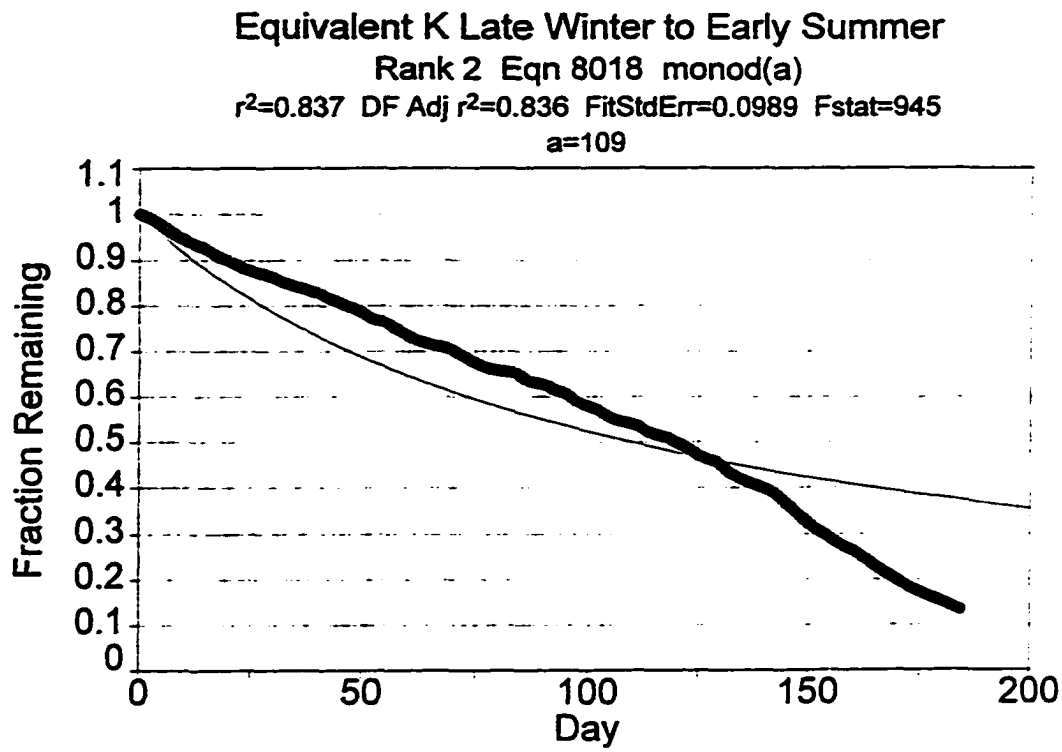
Figure J.9 Equivalent K Late Winter to Early Summer, Linear Fit



Rank 2 Eqn 8018 monod(a)

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.8370048311	0.8361141471	0.0988673976	944.86781389

Parm	Value	Std Error	t-value	90% Confidence Limits	
a	109.2687364	3.596462827	30.38227882	103.3229853	115.2144874

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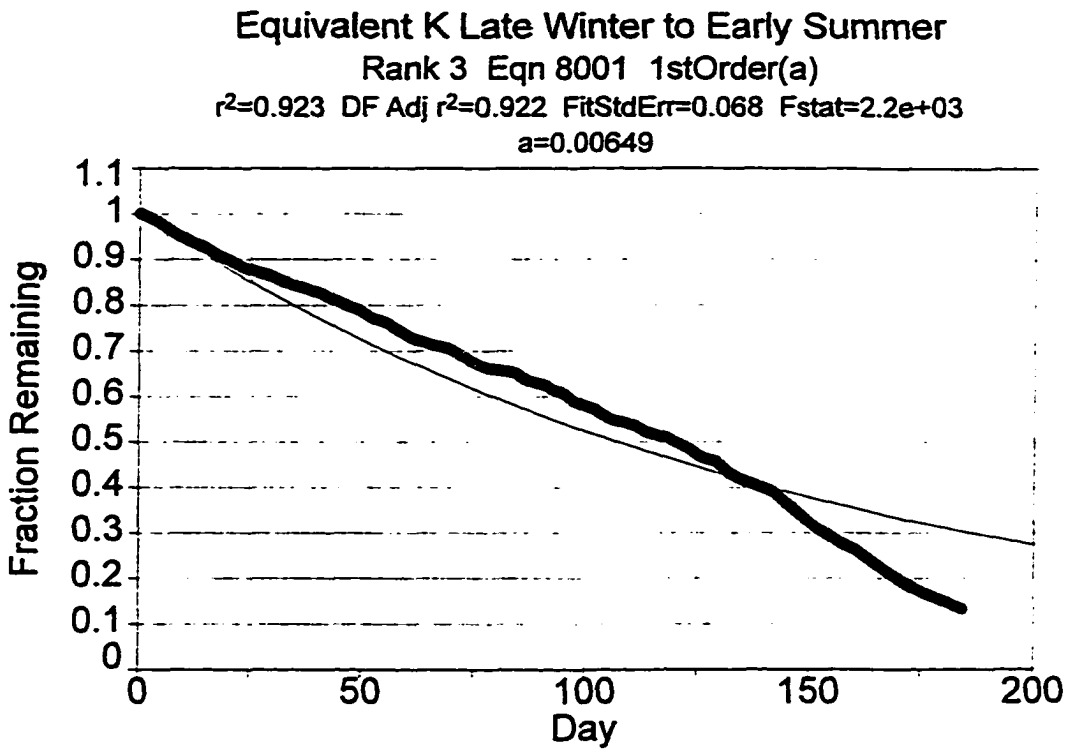
Figure J.10 Equivalent K Late Winter to Early Summer, Rectangular Hyperbola Fit



Rank 3 Eqn 8001 1stOrder(a)

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9227997177	0.9223778583	0.0680417039	2199.4109747

Parm	Value	Std Error	t-value	90% Confidence Limits	
a	0.006489512	0.000108630	59.73935628	0.006309922	0.006669102

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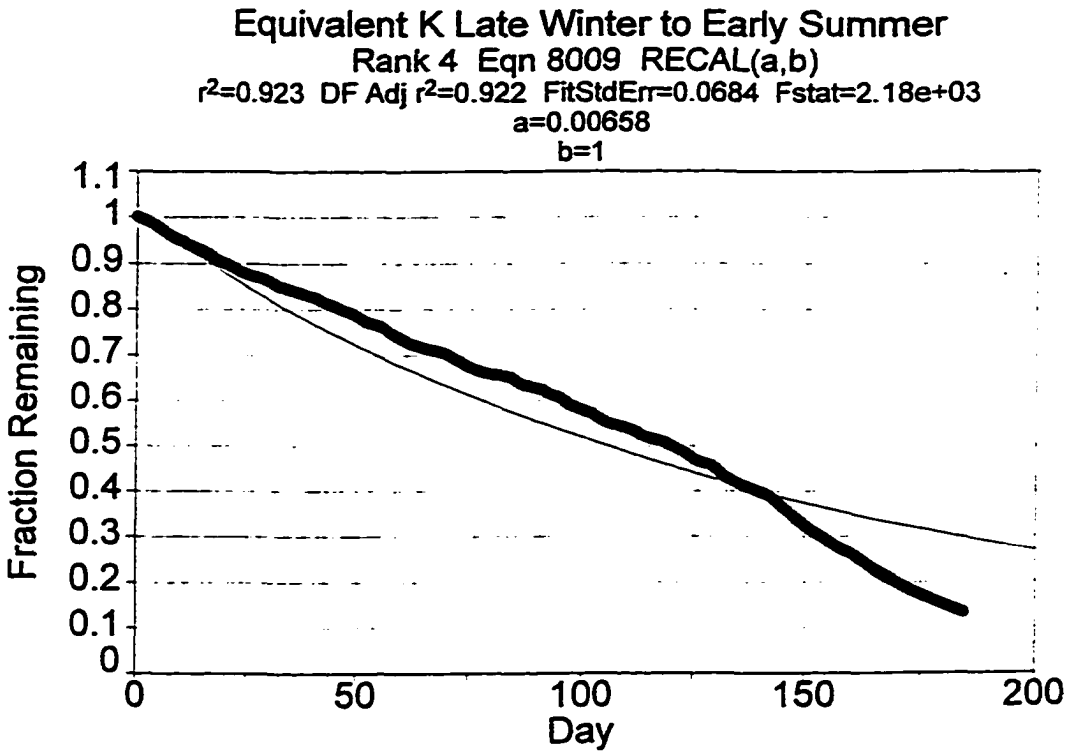
Figure J.11 Equivalent K Late Winter to Early Summer, 1st Order Fit



Rank 4 Eqn 8009 RECAL(a,b)

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9225196983	0.9216682664	0.0683509814	2178.8906482

Parm	Value	Std Error	t-value	90% Confidence Limits	
a	0.006576318	0.000742034	8.862558904	0.005349534	0.007803102
b	1.000000000	0.072663900	13.76199186	0.879866762	1.120133238

Date	Time	File Source
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Figure J.12 Equivalent K Late Winter to Early Summer, RECAL Fit

Vita

Paul Timothy (Tim) Tate was born in 1951 in Sendai, Japan. He was the youngest of five children of American parents, Colonel Ferdinand J. Tate, a 5th generation native of St. Landry Parish, Louisiana, and the late Elizabeth Ladd Tate, a native of the Ithaca area of New York state. Tim attended Catholic elementary schools in the Panama Canal Zone and Alexandria, Virginia, prior to moving to Louisiana with his father's retirement from the Army in 1962. He graduated from Landry High School (now called St. Louis High School) in Lake Charles, Louisiana in 1969, and enrolled at Louisiana State University that year.

In 1973 Tim received his bachelor of science degree in Civil Engineering from L.S.U. and went to work for the US Army Corps of Engineers in New Orleans. In 1975 he returned to graduate school at L.S.U. and received his master of science degree in Civil Engineering in 1976. Also in 1976 he married the former Evie Lynn Zumo. Over the next decades they became the parents of Adam Timothy Tate (1977), John Joseph Tate (1984), and Laura Clare Tate (1988). Meanwhile Tim worked in Baton Rouge for local consulting engineering firms in the fields of water resources and environmental engineering.

In 1989 Tim returned to part-time classes at L.S.U. and eventually decided to pursue a doctoral degree. By mid-1996 he had completed the course work and in October 1996 was presented with an opportunity to return to academia full time to execute the required research. In December 1998 he anticipates receiving his degree of Doctor of Philosophy in Civil Engineering, God willing, after attending L.S.U. during parts of four decades.

DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Paul Timothy Tate

Major Field: Civil Engineering

Title of Dissertation: Significance of the Effect of Nitrogen Application on the Engineered Bioremediation of Crude Oil in a Salt Marsh

Approved:

Major Professor and Chairman

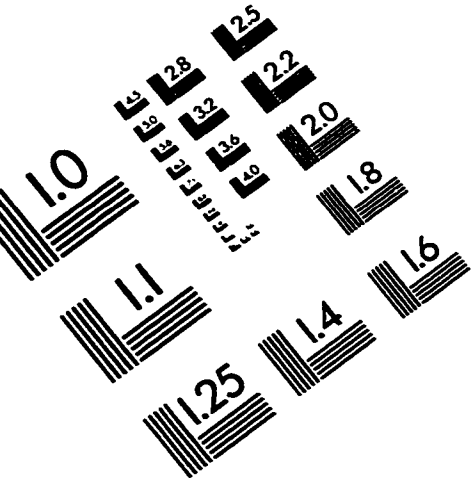
Dean of the Graduate School

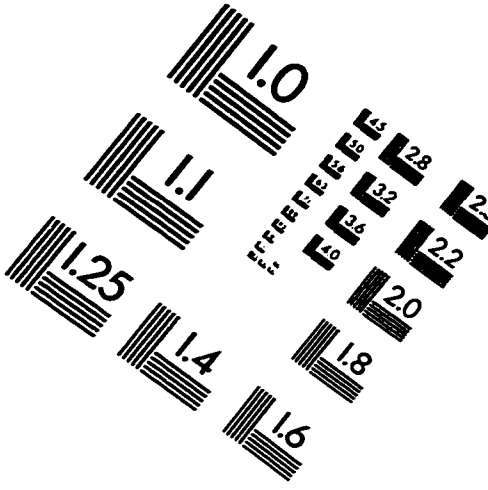
EXAMINING COMMITTEE:

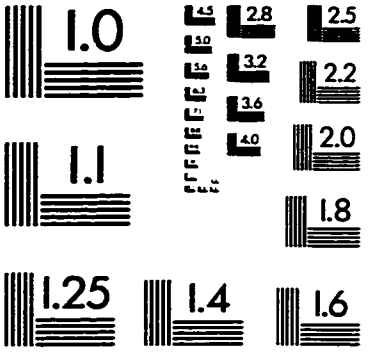
Date of Examination:

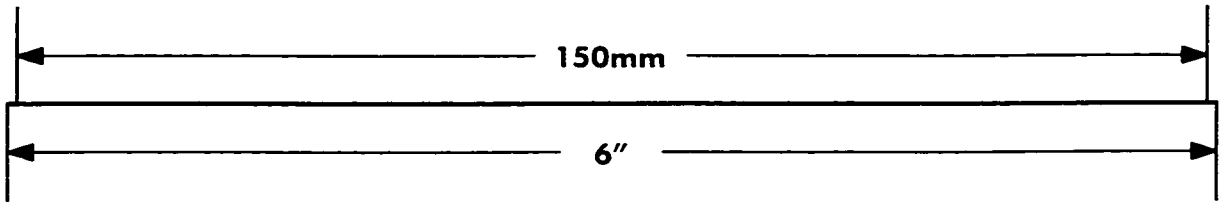
21 September 1998

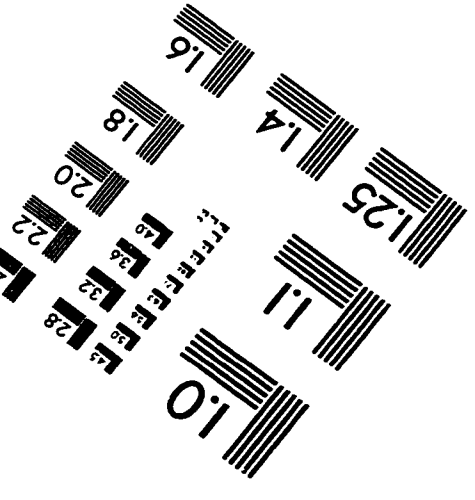
IMAGE EVALUATION TEST TARGET (QA-3)

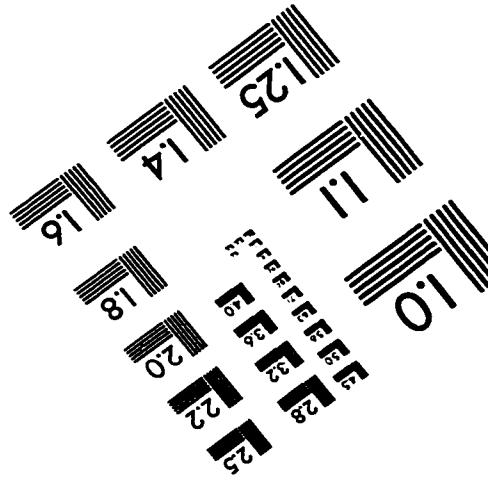












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